
National Aeronautics and Space Administration
NASA
Overview of Significant SWx Events in 2012
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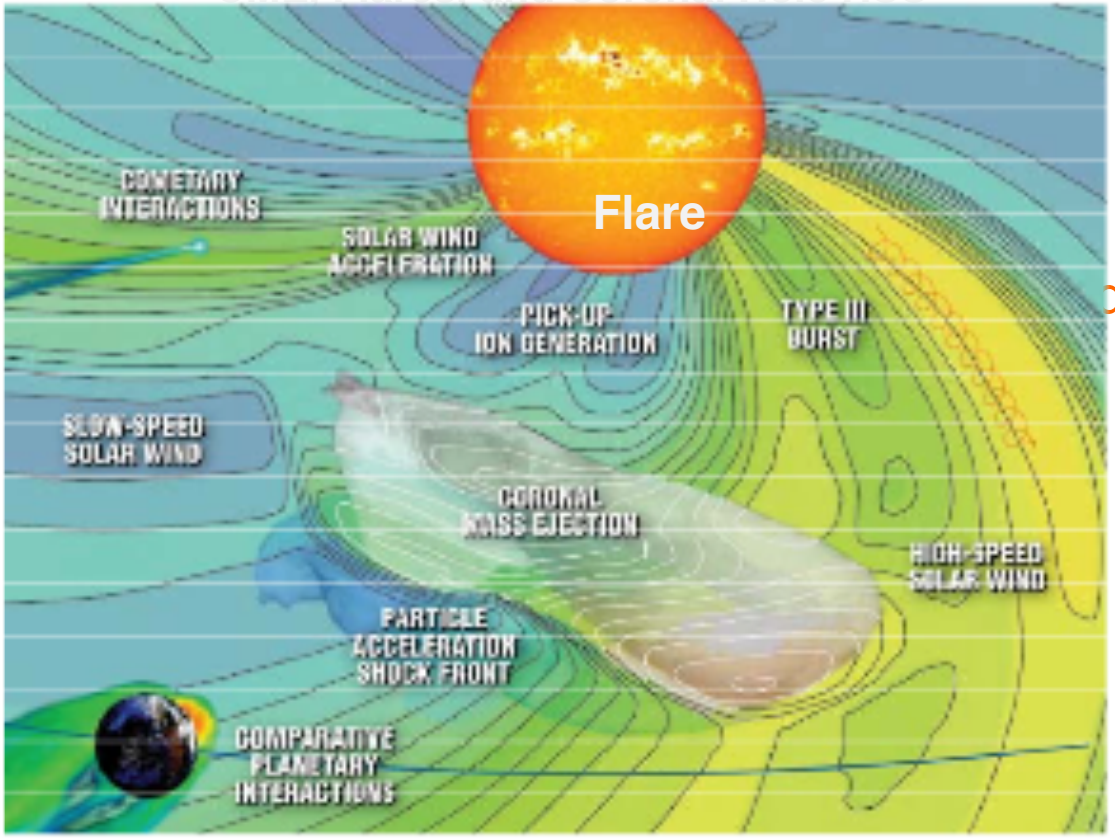
Outline

- Types of Space Weather Storms
  - Solar energetic ion storms (everywhere)
  - Radiation belt electron storms (Earth/Earth-like planets)
  - Geomagnetic storms (Earth and Earth-like)
  - Radio Blackouts
- Significant SWx Events in 2012

The Sun
Maker of Space Weather



CME, Flares, and Coronal Hole High speed solar wind

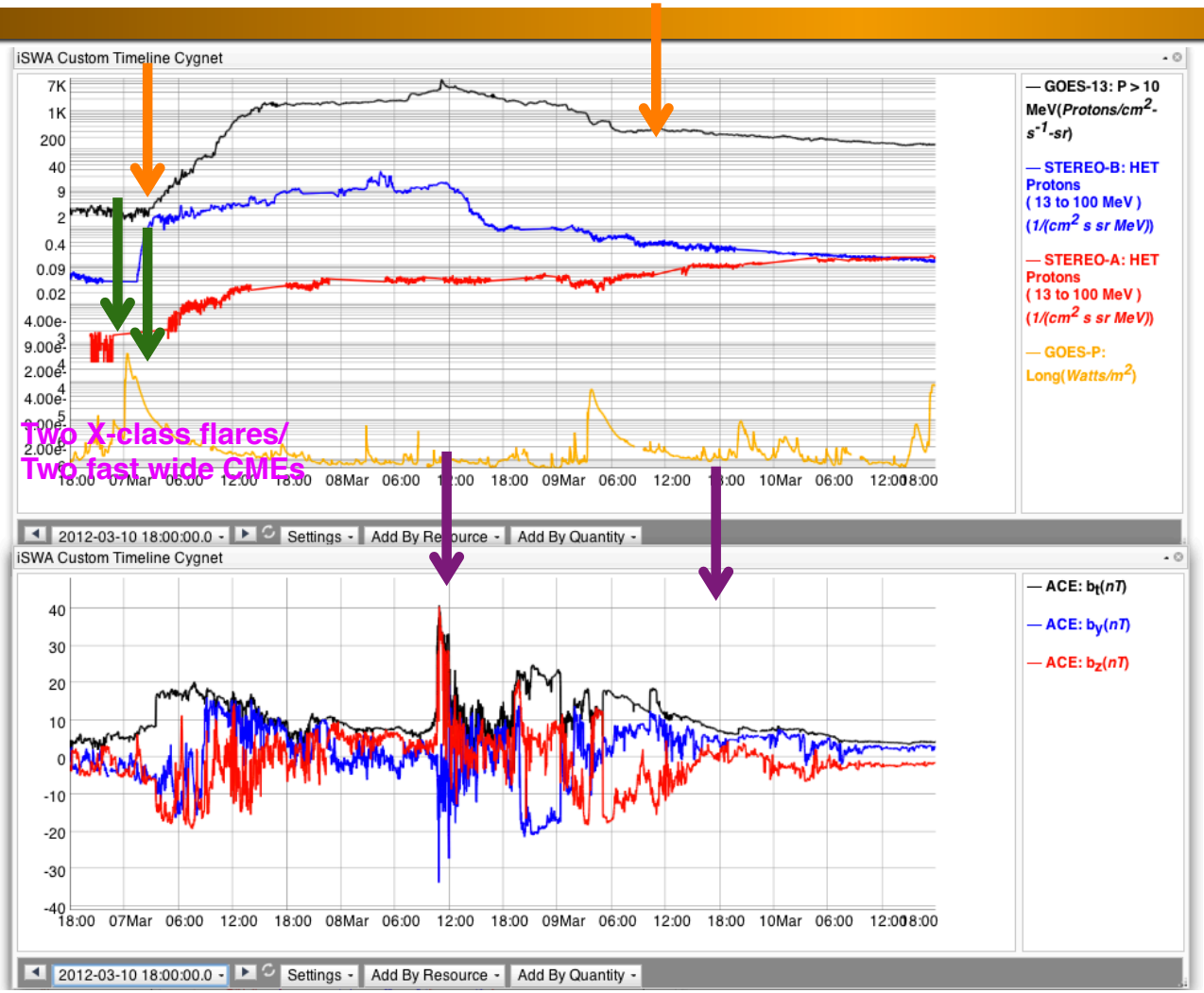
Three very important solar wind disturbances/structures for space weather

- ✓**Radiation storm**
  - **proton radiation (SEP) <Flare/CME>**
  - **electron radiation <CIR HSS/CME>**
- ✓**Radio blackout storm <Flare>**
- ✓**Geomagnetic storm**
  - **CME storm (can be severe)**
  - **CIR storm (at most moderate)**

Flare and CME demo

Space Weather Effects and Timeline

(Flare and CME)



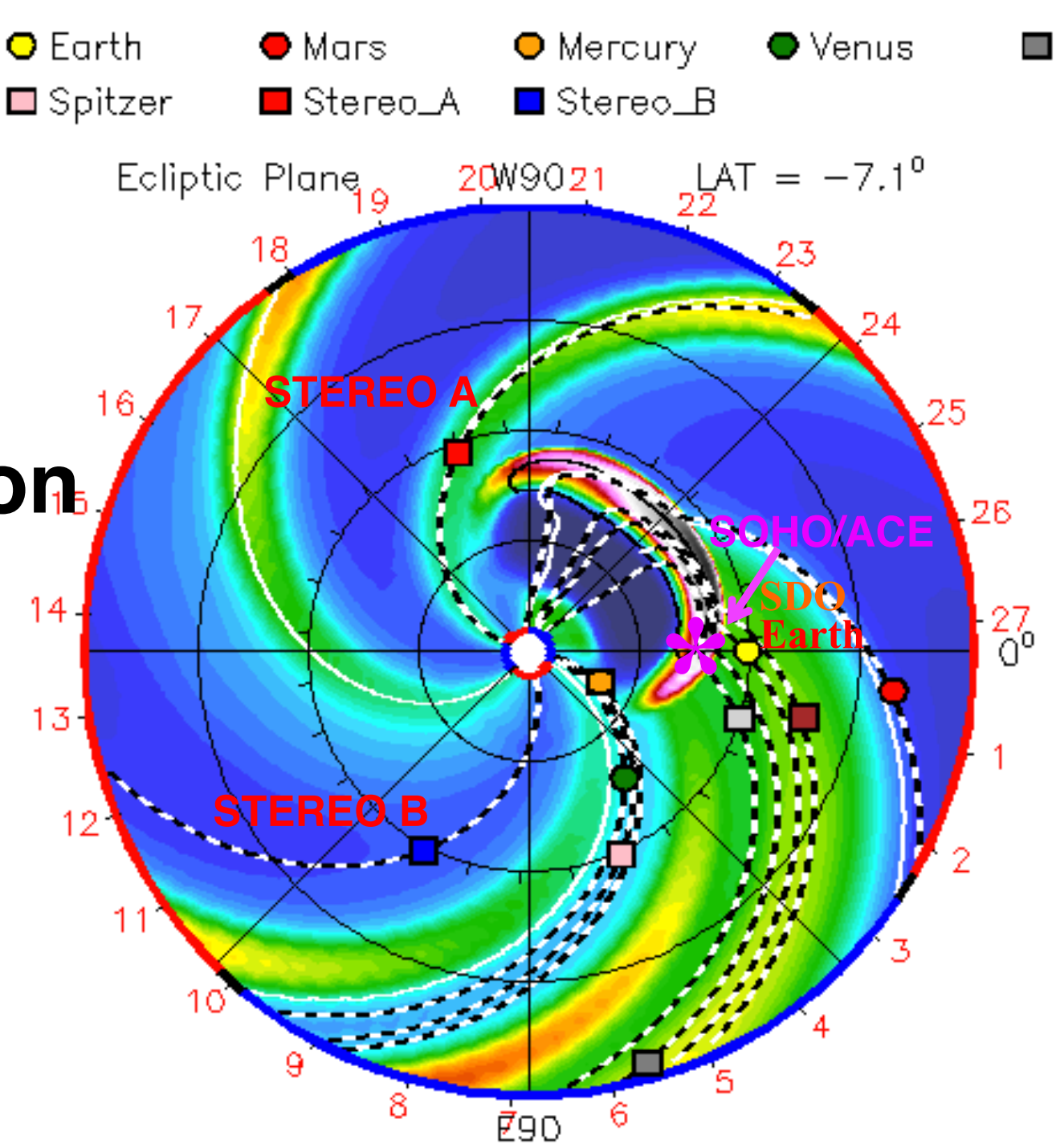
Flare effects at Earth:
~ 8 minutes (radio blackout storms)
Duration: minutes to hours

SEP radiation effects reaching Earth: 20 minutes – 1hour after the event onset
Duration: a few days

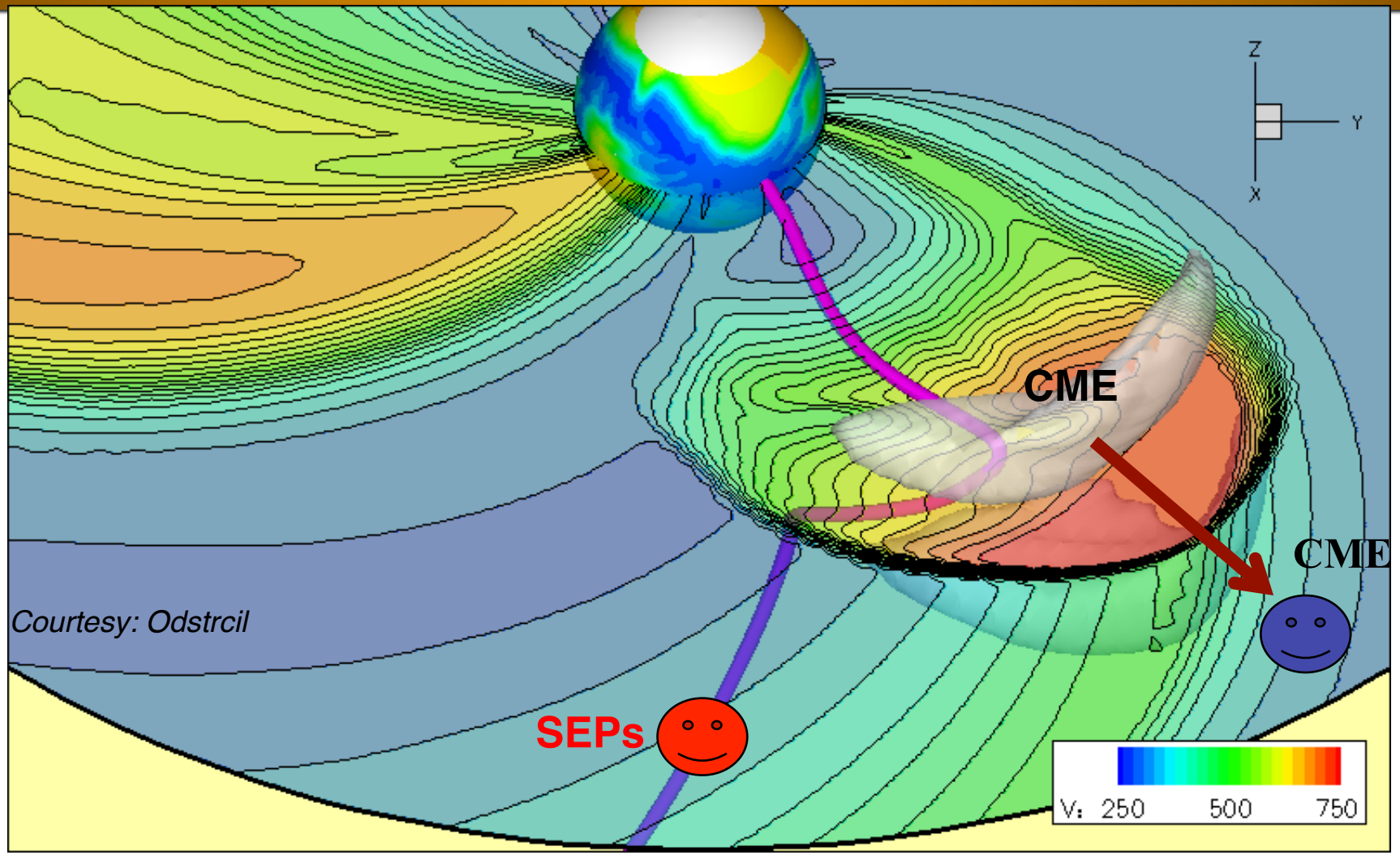
CME effects arrives @ Earth: 1-2 days (35 hours here)
Geomagnetic storms: a couple of days

Types of Storms

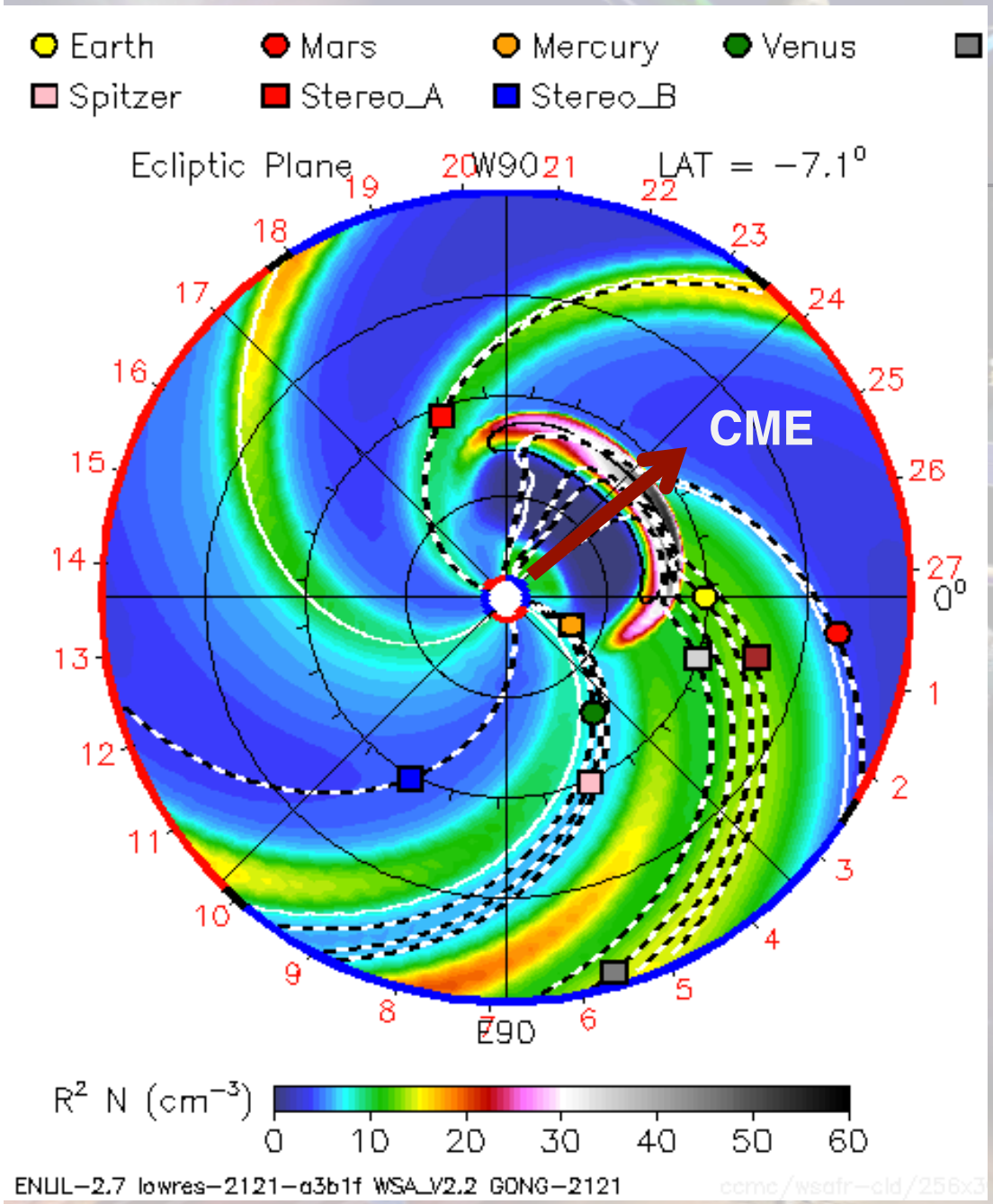
Orientation



CME and SEP path are different



CME: could get deflected, bended, but more or less in the radial direction



Important distinction

Ion Radiation storm vs
Geomagnetic storm

CME impact and SEP (Solar Energetic Particle) impact are different

CME impact @ Earth: Geomagnetic Storm

Radiation storm @ Earth from SEPs

CME speed: 300 – 3500 km/s
SEPs: fraction of c
Light speed c: 3 x10^5 km/s

SEPs: ion radiation storms

Potentially affect everywhere in the solar system

Courtesy: SVS@ NASA/GSFC

Geomagnetic Storms:

CME interaction with Earth (magnetic field)

Geomagnetic storms due to CIRs are at most moderate

Coronal Hole HSS

- Is one important space weather contributor too!
- Particularly for its role in enhancing electron radiation levels in the near-Earth environment and for substantial energy input into the Earth's upper atmosphere
- May be more hazardous to Earth-orbiting satellites than CME-related magnetic storm particles and solar energetic particles (SEP)

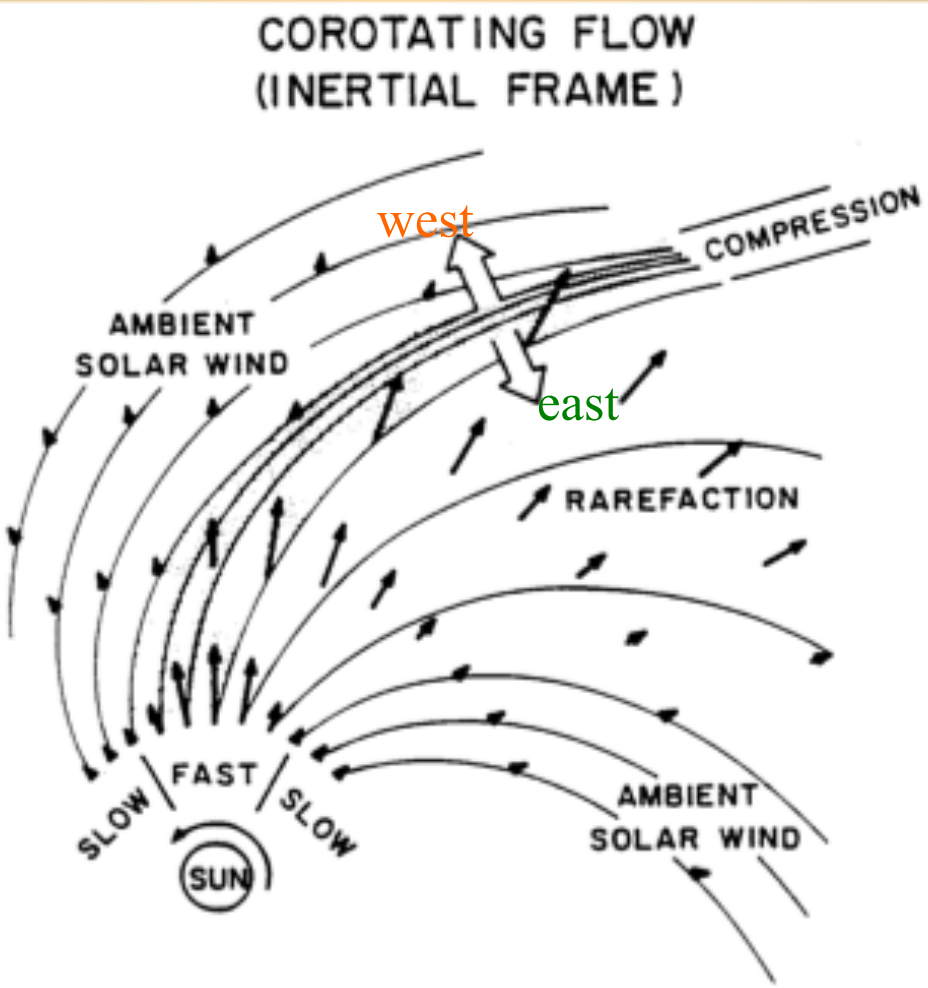
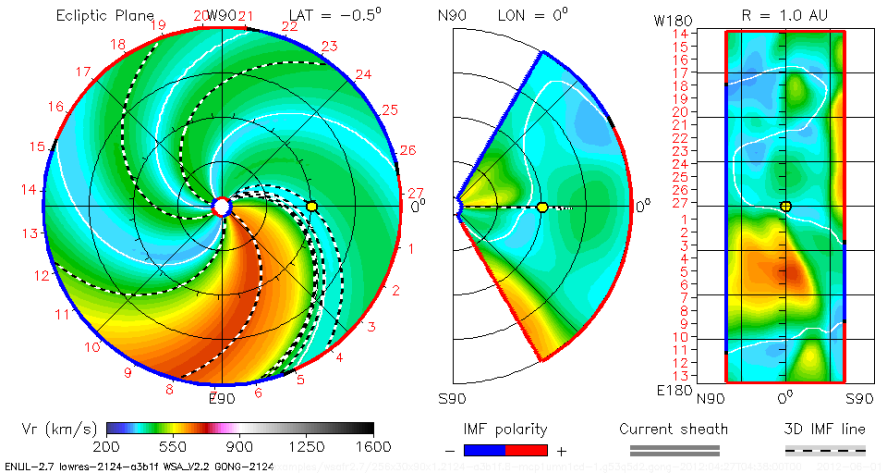
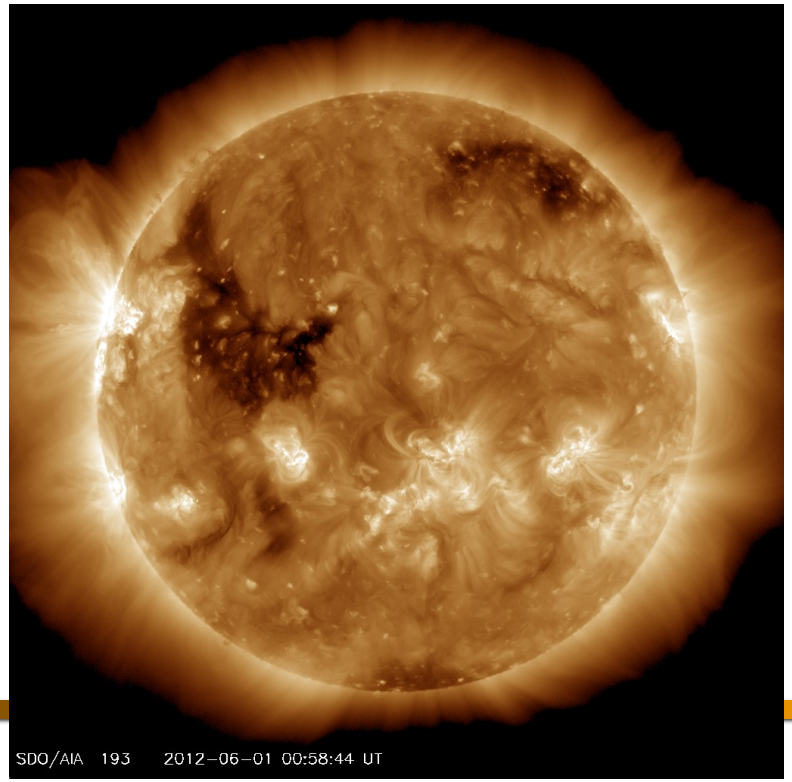


Figure 6. Schematic illustrating 2-D corotating stream structure in the solar equatorial plane in the inner heliosphere (from Pizzo, 1978).

2012-06-01T19:00 2012-05-10T01 +22.73 days

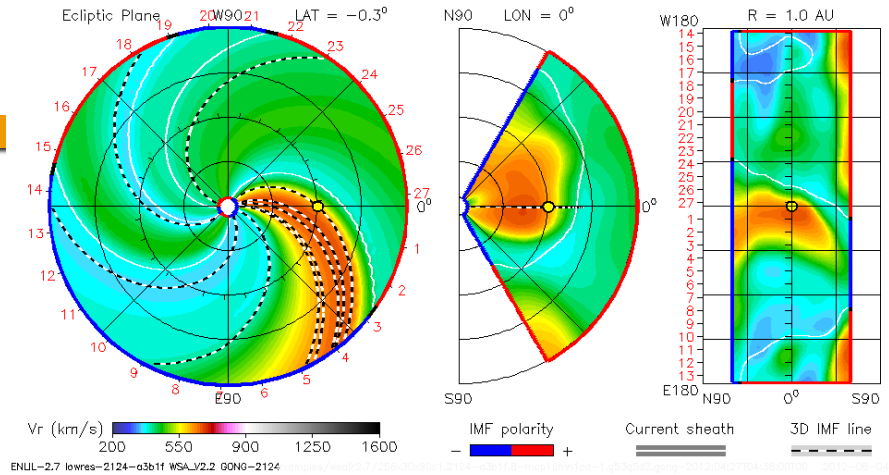
Earth

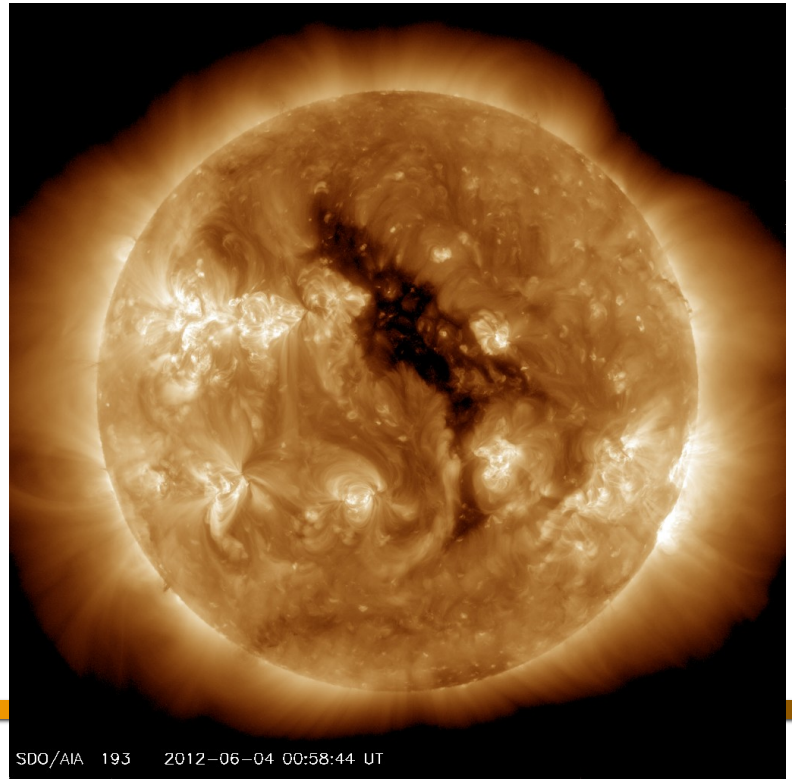




2012-06-04T10:00 2012-05-12T17 +22.73 days

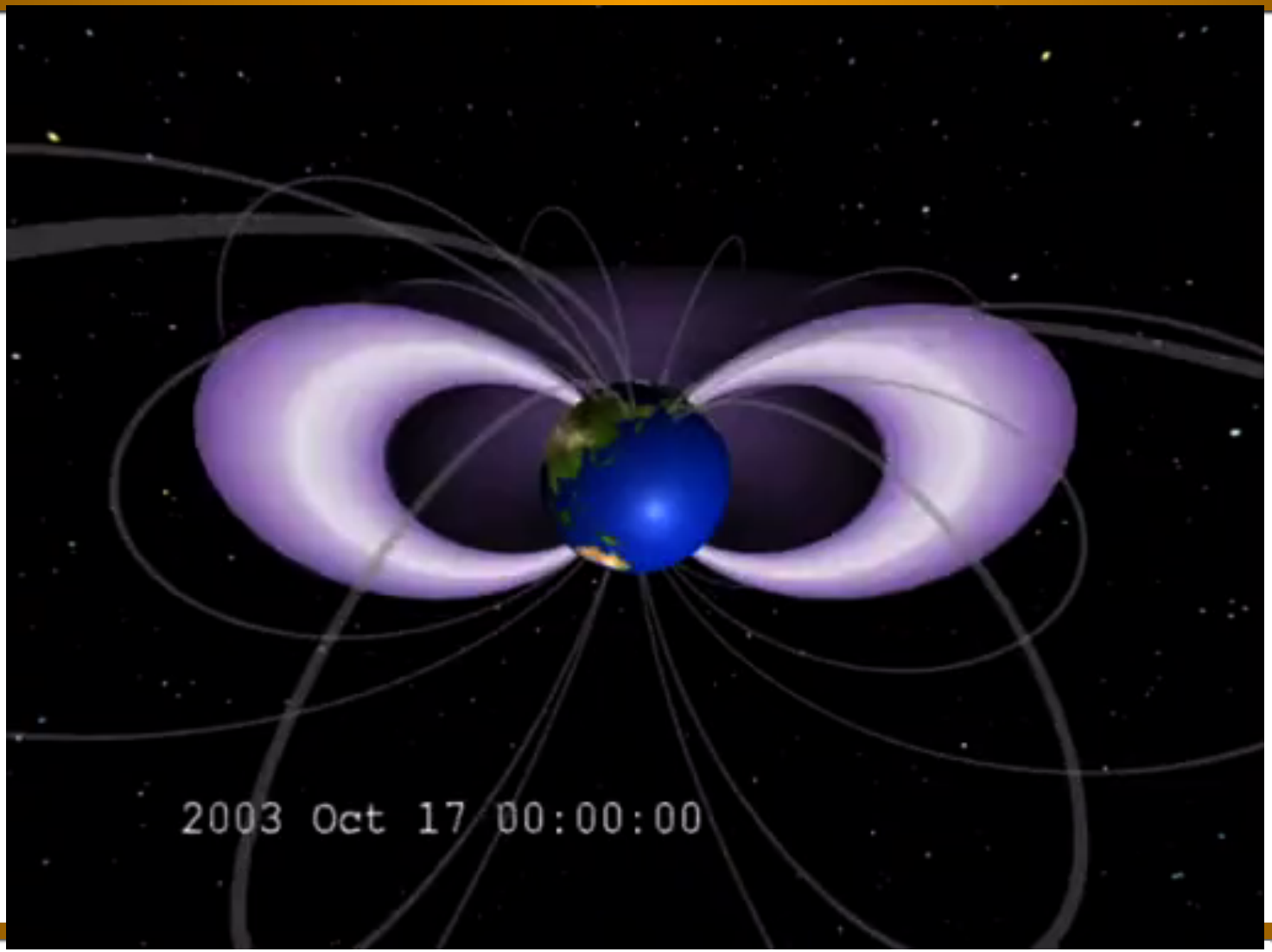
Earth



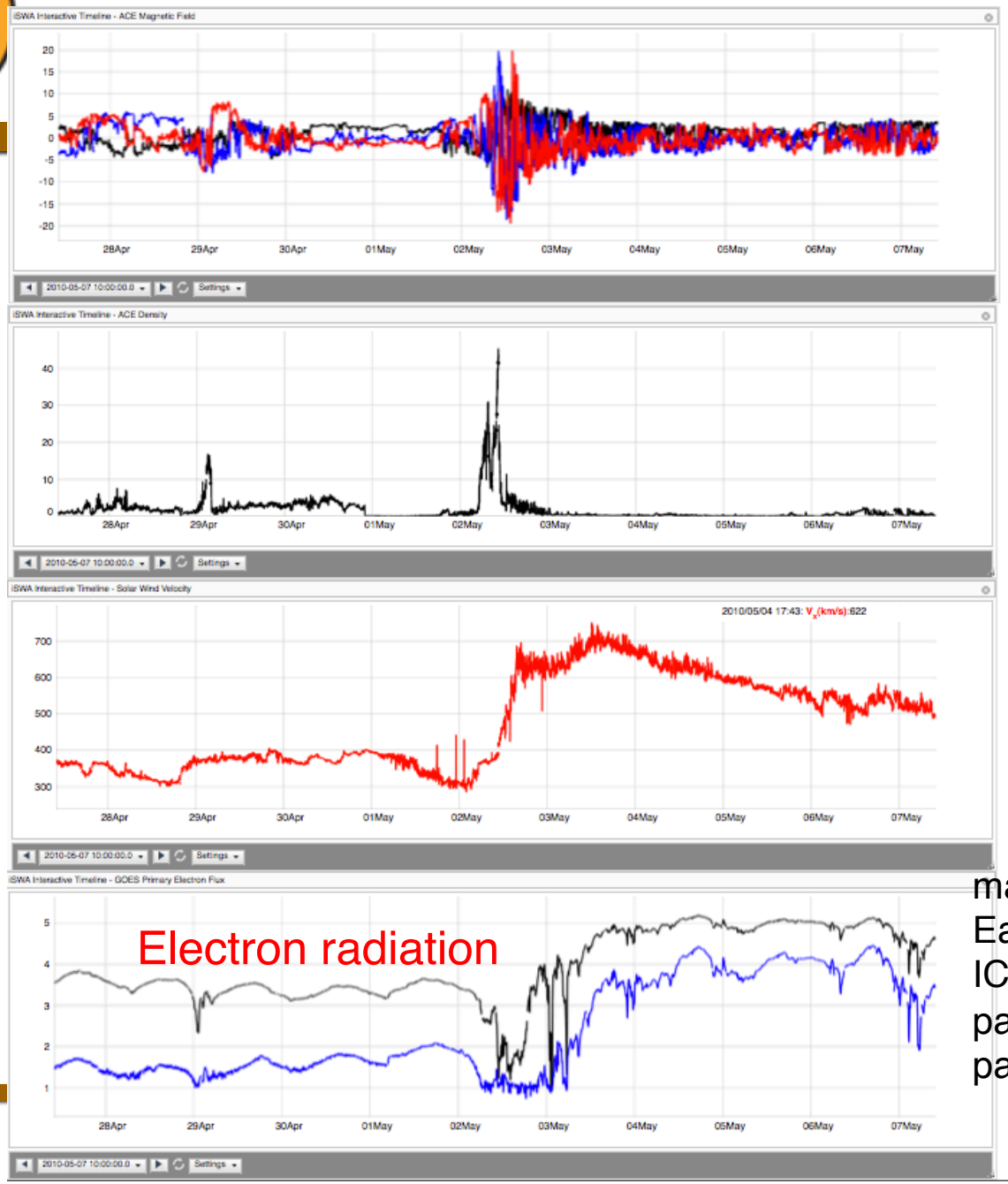


Electron Radiation:

Radiation belt (Earth, Jupiter, Saturn, Uranus, Neptune)



RBSP: launched successfully on August 30, 2012



Clean HSS

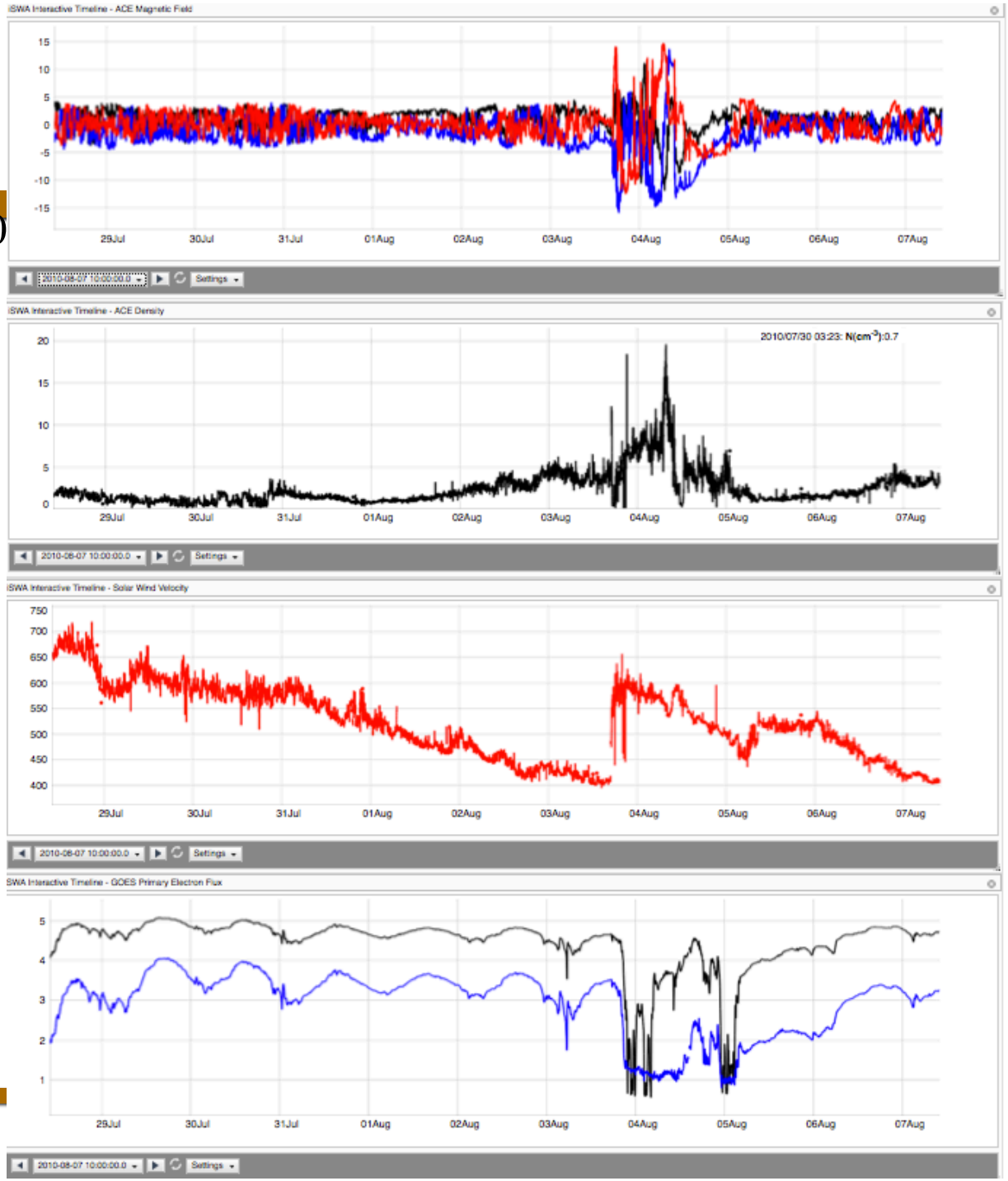
May 2, 2010

Dense (20-30 cc), HSS

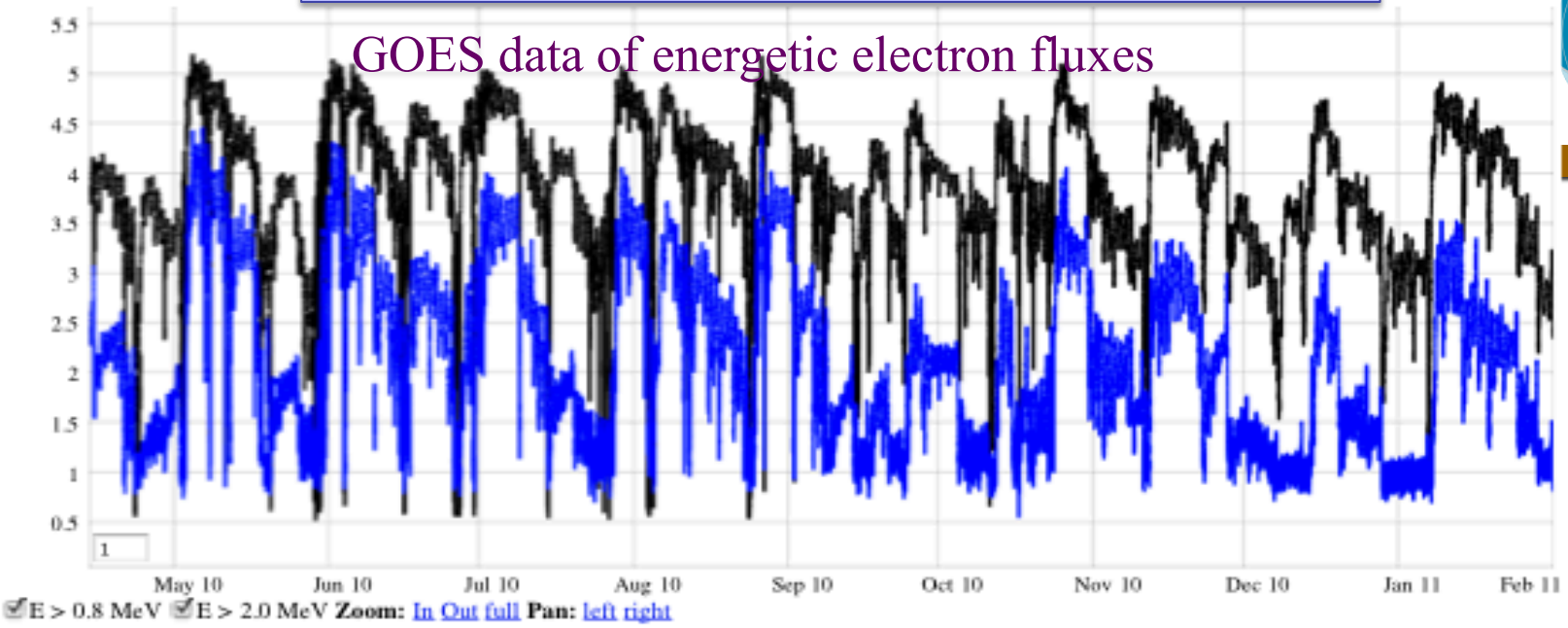
IMFBz: -18 nT

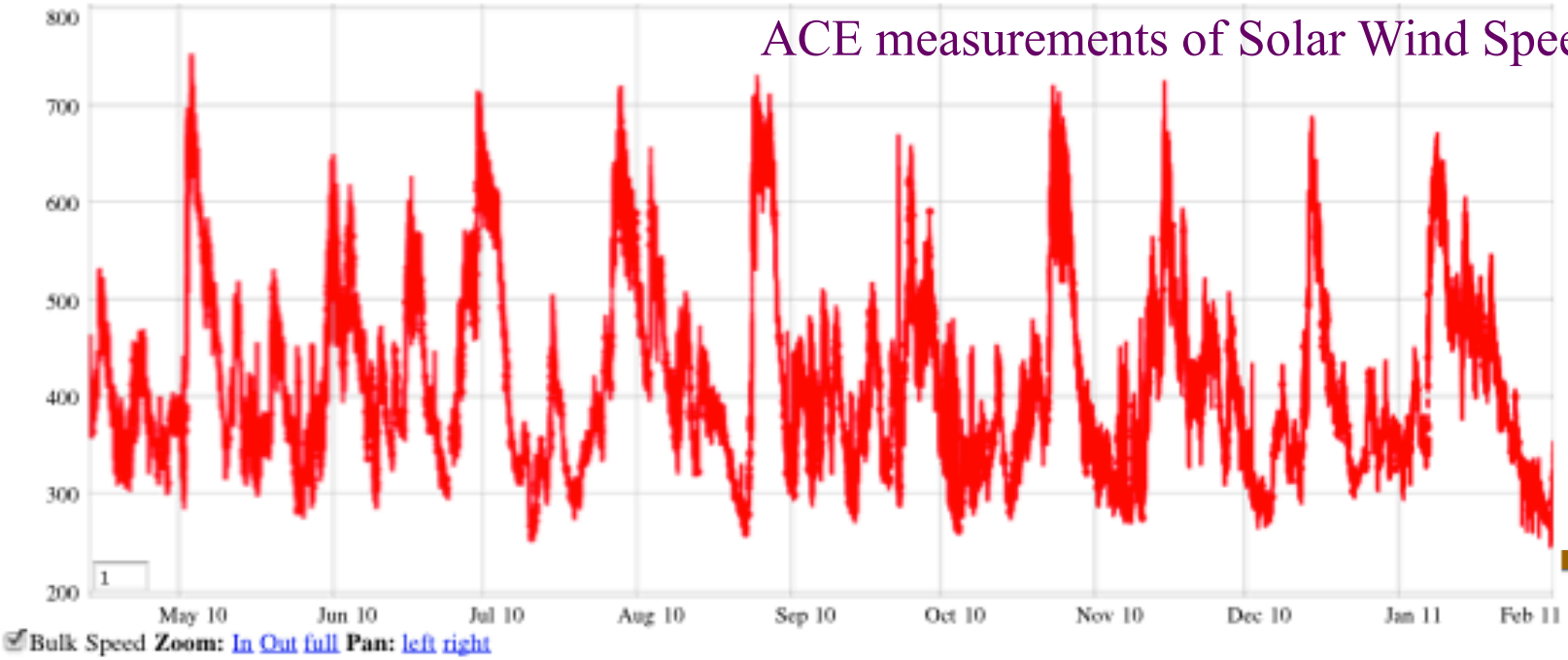
may be more hazardous to Earth-orbiting satellites than ICME-related magnetic storm particles and solar energetic particles

Aug 3, 2010


ISWA Interactive Timeline - ACE Magnetic Field
15
10
5
0
-5
-10
-15
29Jul
30Jul
31Jul
01Aug
02Aug
03Aug
04Aug
05Aug
06Aug
07Aug
Settings
ISWA Interactive Timeline - ACE Density
20
15
10
5
0
2010/07/30 03:23: N(cm-3):0.7
ISWA Interactive Timeline - Solar Wind Velocity
750
700
650
600
550
500
450
400
ISWA Interactive Timeline - GOES Primary Electron Flux
5
4
3
2
1

HSS and radiation belt electron flux enhancement





Two types of external solar wind drivers for Outer Radiation Belt

- ✓ CME storms
  peak flux penetrate closer to Earth
- ✓ CIR storms (due to high speed solar wind streams)
  peak around geosynchronous orbit

Significant SWx Events in 2012

Increase in solar activities in comparison to 2010 and 2011

Significant SEP Events

- Three major SEP events
  - Around Earth:
    - Jan 23, 2012 event: peak flux 6310 pfu @ Jan 24/15:30 UT – largest since November 2003
    - March 7, 2012 event: peak flux 6530 pfu@ Mar 08/11:15 UT – largest since November 2003
  - Around STEREO A
    - **23 July 2012 event: peak flux 454 pfu/MeV for 13 -100 MeV protons → ~ 4.5x10^4 pfu**

The two largest/extreme SEP events since 1976 (the > 10 MeV proton flux @ geo orbit >10^4 pfu)

- ✓ 1989 Oct 20 **40,000 pfu**
- ✓ 1991 Mar 24 **43,000 pfu**

- SEP event trend (The > 10 MeV proton flux exceeding 10 pfu @ Earth)
  - 2010 1 event
  - 2011 8 events
  - 2012 15 events

>100 pfu
2010 -2011: 0 event
2012: 6 events

First GLE event of Solar Cycle 24
May 17, 2012
AR 1476

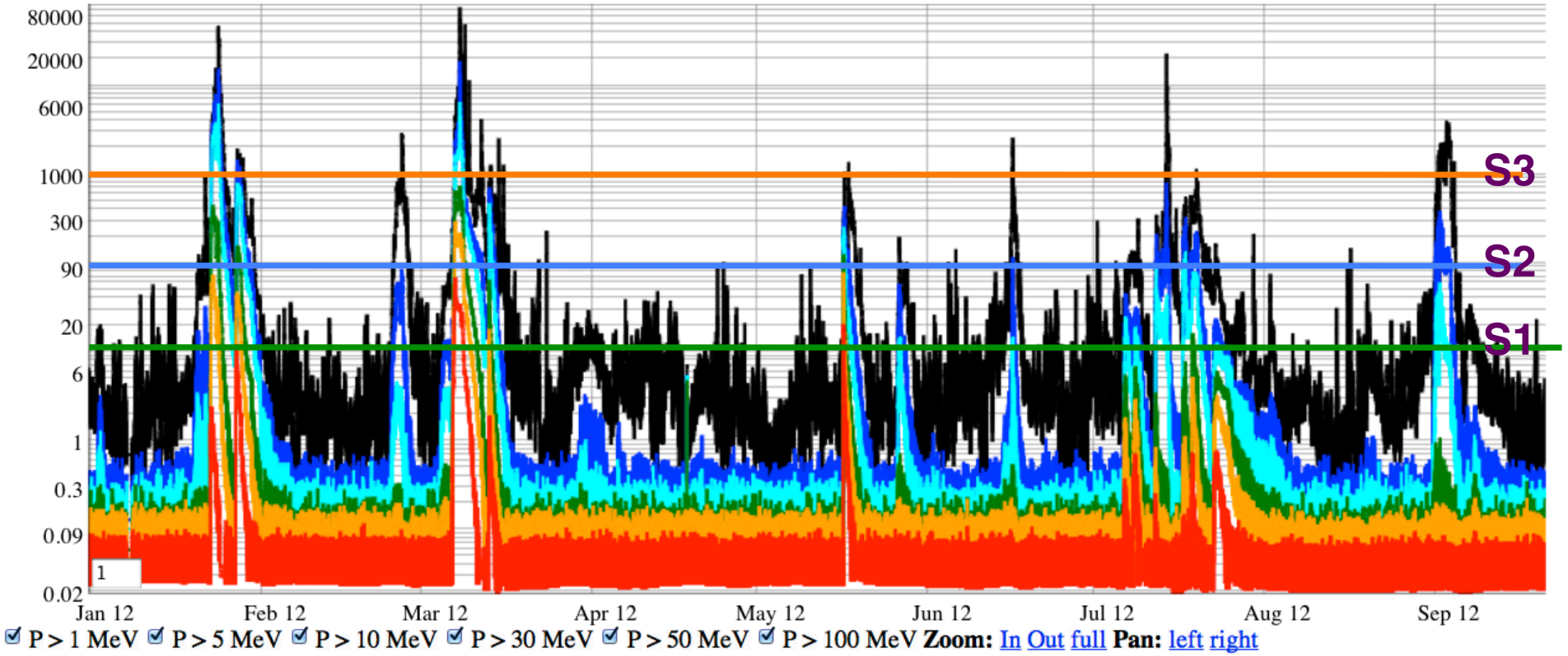
Significant Geomagnetic Storms in 2012

- Six major (Dstmin <-100 nT) geomagnetic storms in 2012
  - **Dstmin = -133 nT** on March 9, 2012 (March 7, 2012 CMEs, the largest SEP event at Earth too)
  - **Dstmin = -127** nT on July 15, 2012 (July 12, 2012 CME)
  - **Dstmin=-107 nT** on April 24, 2012 at 05:00 UT (CME mixed with HSS)
  - **Dstmin=-143 nT** on Oct 1, 2012 (Sep 28, 2012 CME)
  - **Dstmin=-111 nT** on Oct 9, 2012 (CME) - Van Allen Probes Mission
  - **Dstmin = -109 nT** on Nov 14, 2012 (two average CMEs)

- more abundant year 2011 (three major geomagnetic storms – CME driven)
  - **Dstmin=-107 nT** at 2011-08-06T04:00Z (CMEs)
  - **Dstmin=-101 nT** at 2011-09-26T24:00Z (CME)
  - **Dstmin=-132 nT** at 2011-10-25T02:00Z (CMEs)

SEPs @ Earth 2012

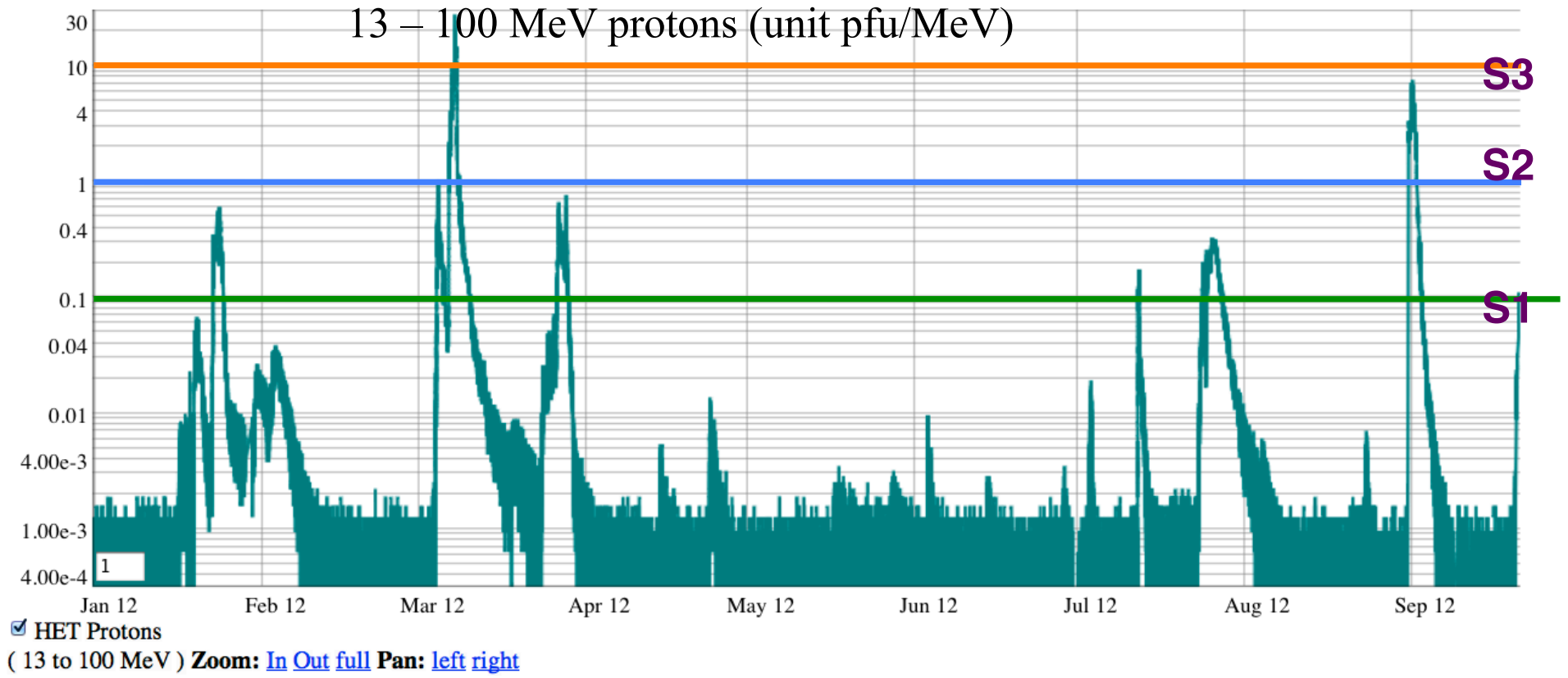
Cyan: for the > 10 MeV proton flux



S1 (>10 pfu): 14 events
S2 (>100 pfu): 6 events
S3 (>1000 pfu): 2 events

Rick Mullinix and David Berrios

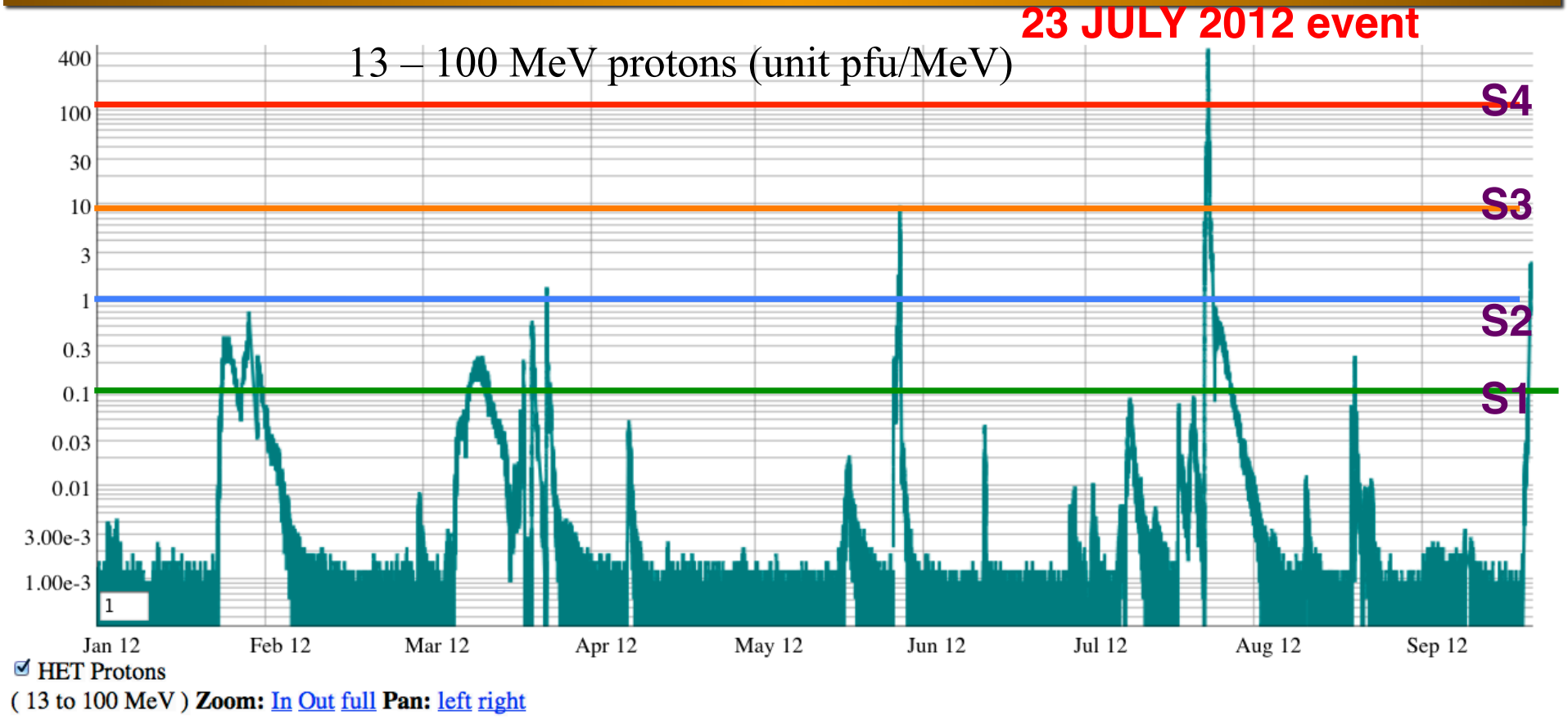
SEPs @ STEREO B (year 2012)



Exceeding 10 pfu 9 events
Exceeding 100 pfu: 2 events
Exceeding 1000 pfu: 1 event

Rick Mullinix and David Berrios

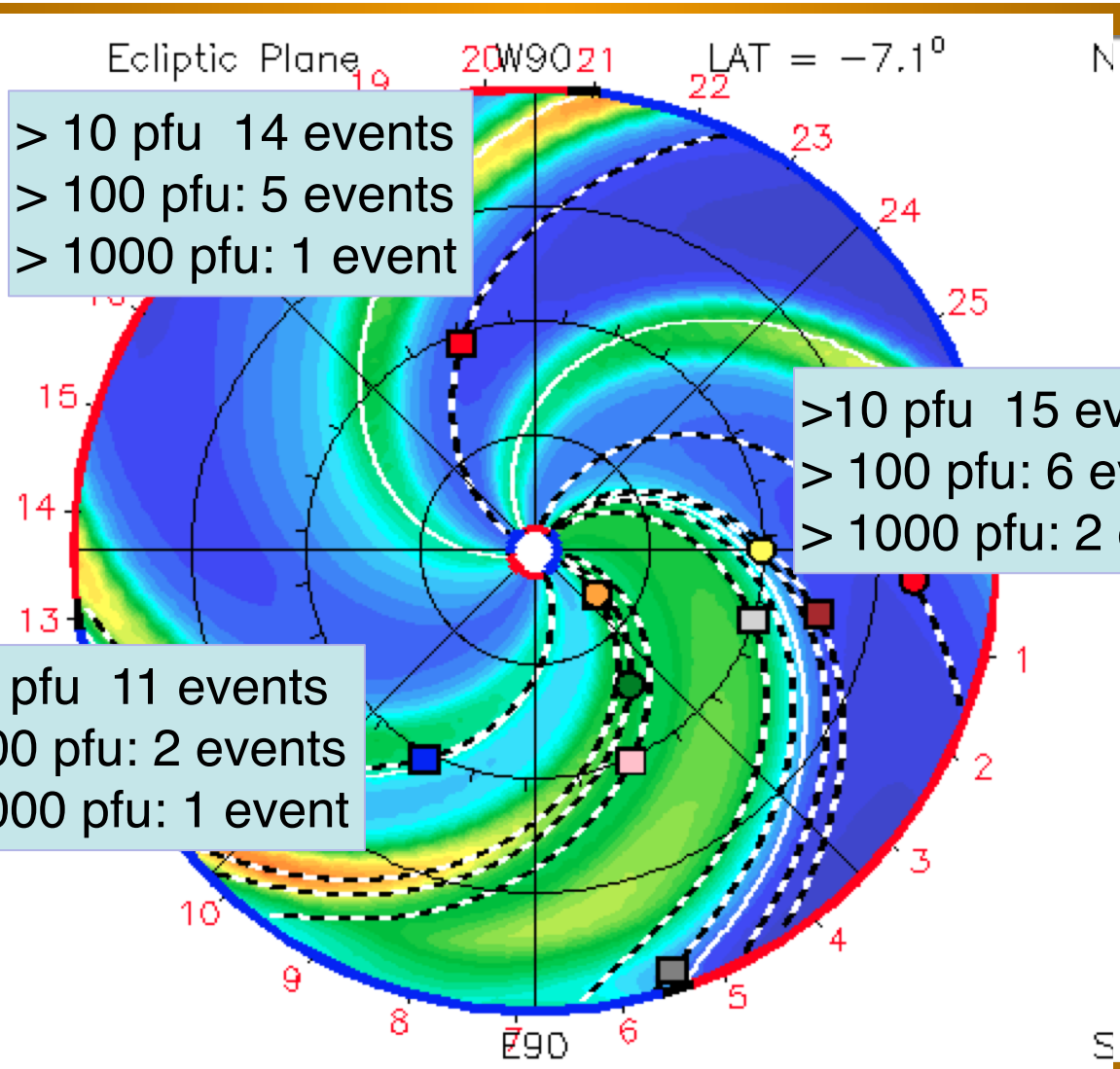
SEPs @ STEREO A (year 2012)



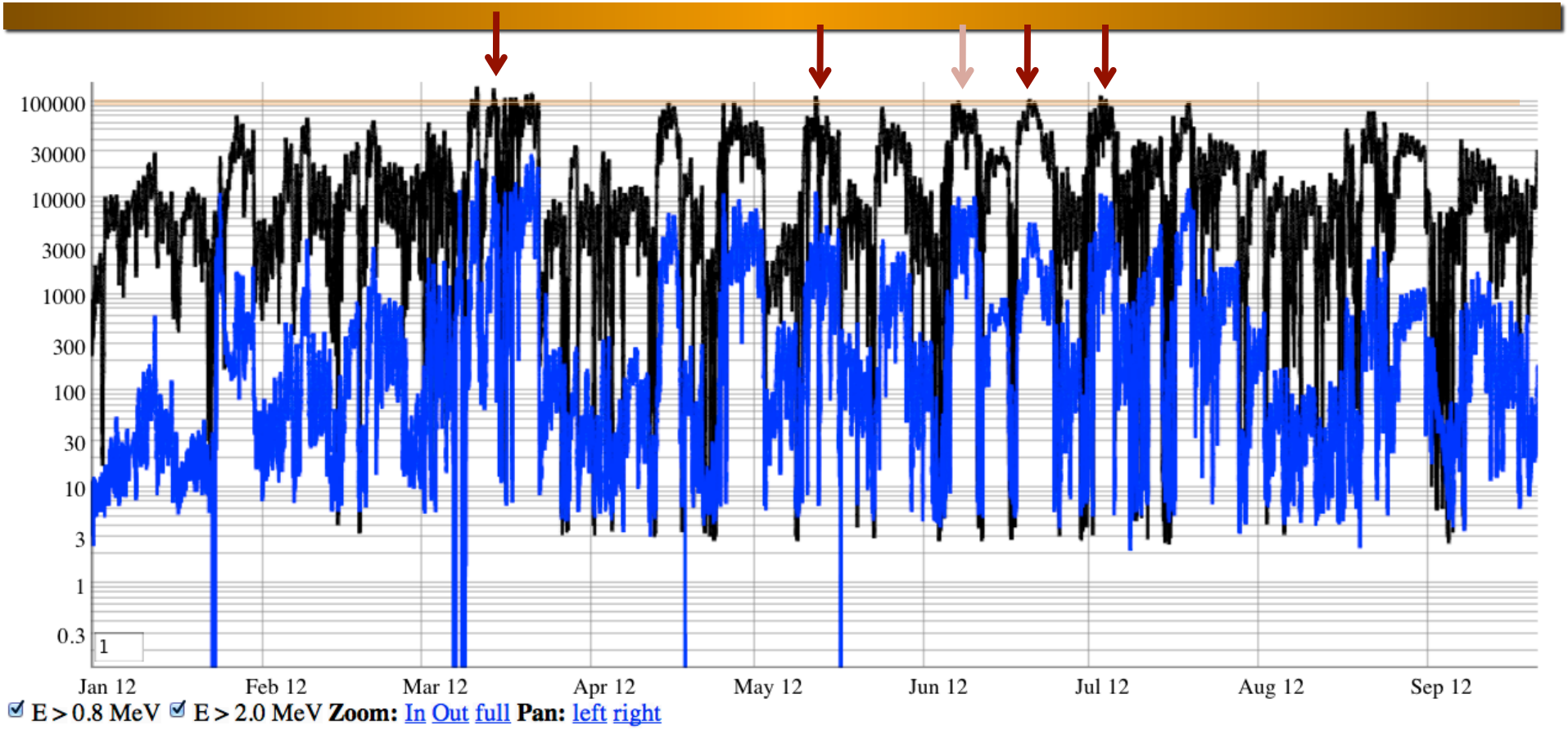
Exceeding 10 pfu 9 events
Exceeding 100 pfu: 5 events
Exceeding 1000 pfu: 1event

Rick Mullinix and David Berrios

SEP event spatial distribution



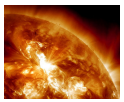
Electron radiation measured @ GOES



Most of them: from aftermath of CME(s)

One: High Speed Solar Wind Streams from a coronal hole

Rick Mullinix and David Berrios



Highlights of Special SWx Events

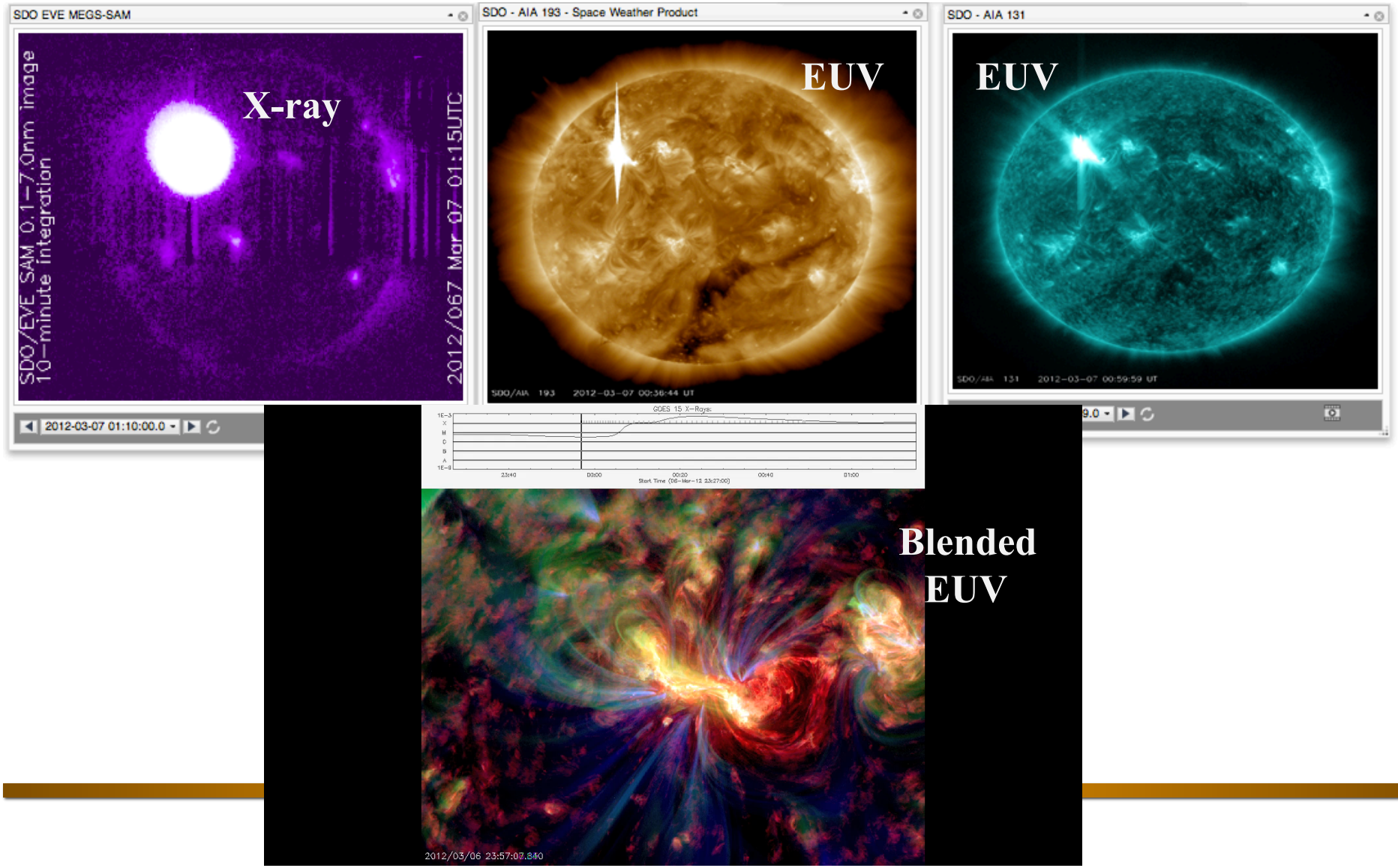
Three unique active regions

AR1520, AR1476, AR1429

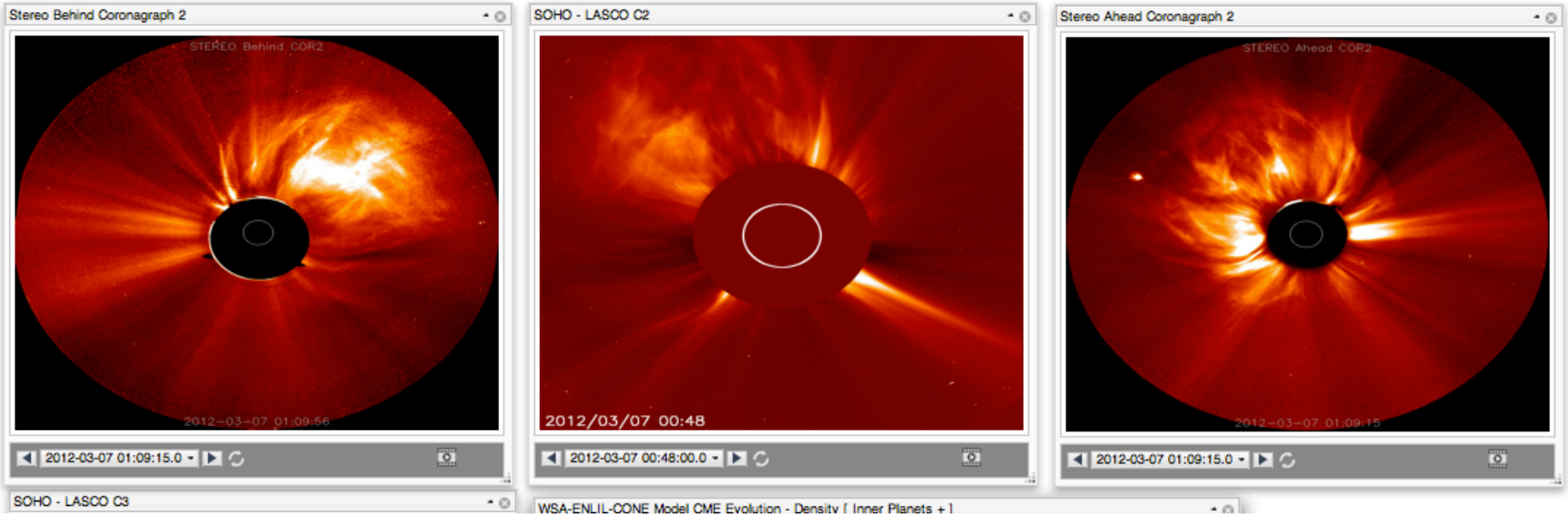
The 7 March 2012 event

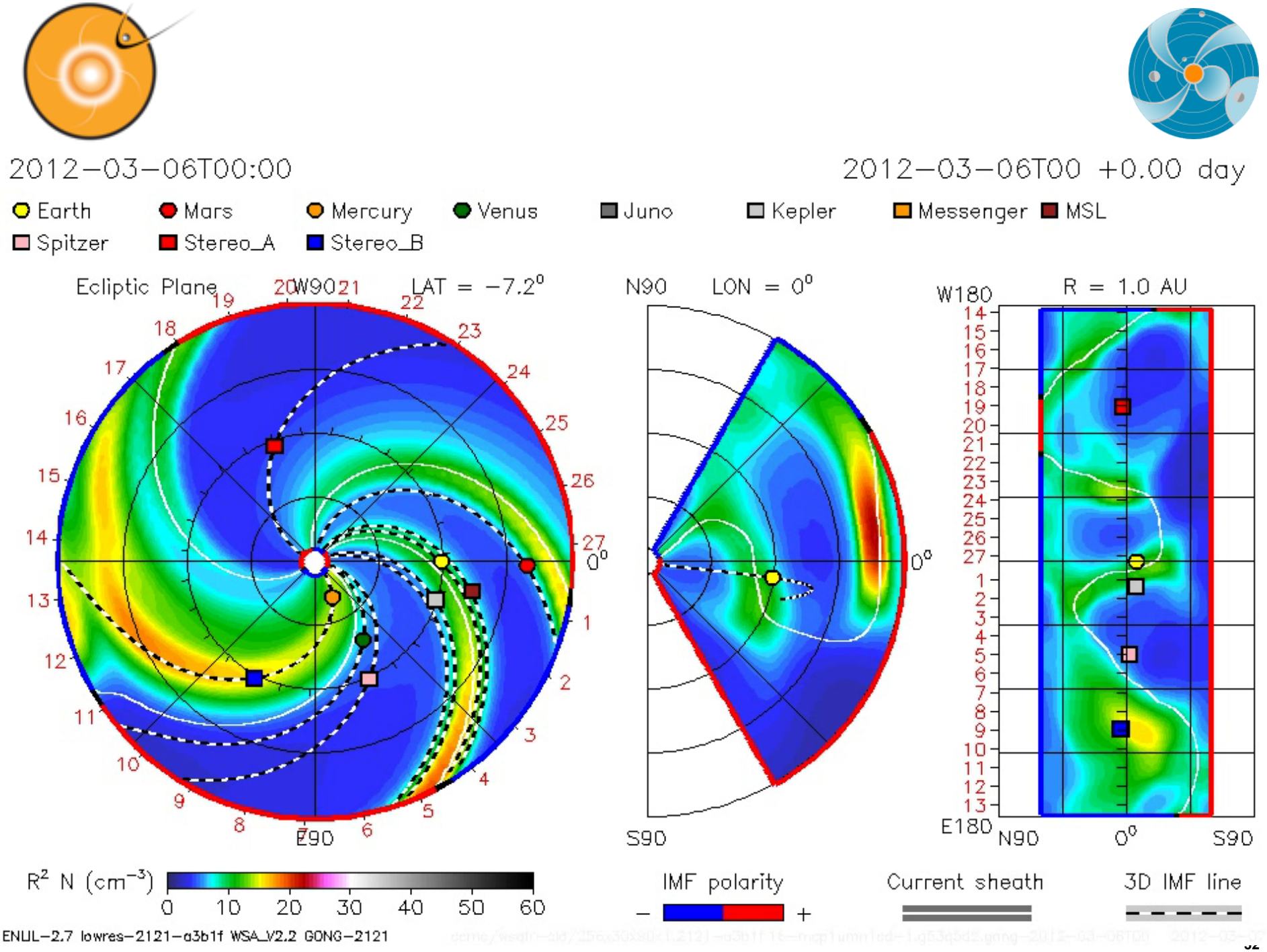
2012 March 7 X5.4/X1.3 flares

Most pronounced in x-ray and EUV

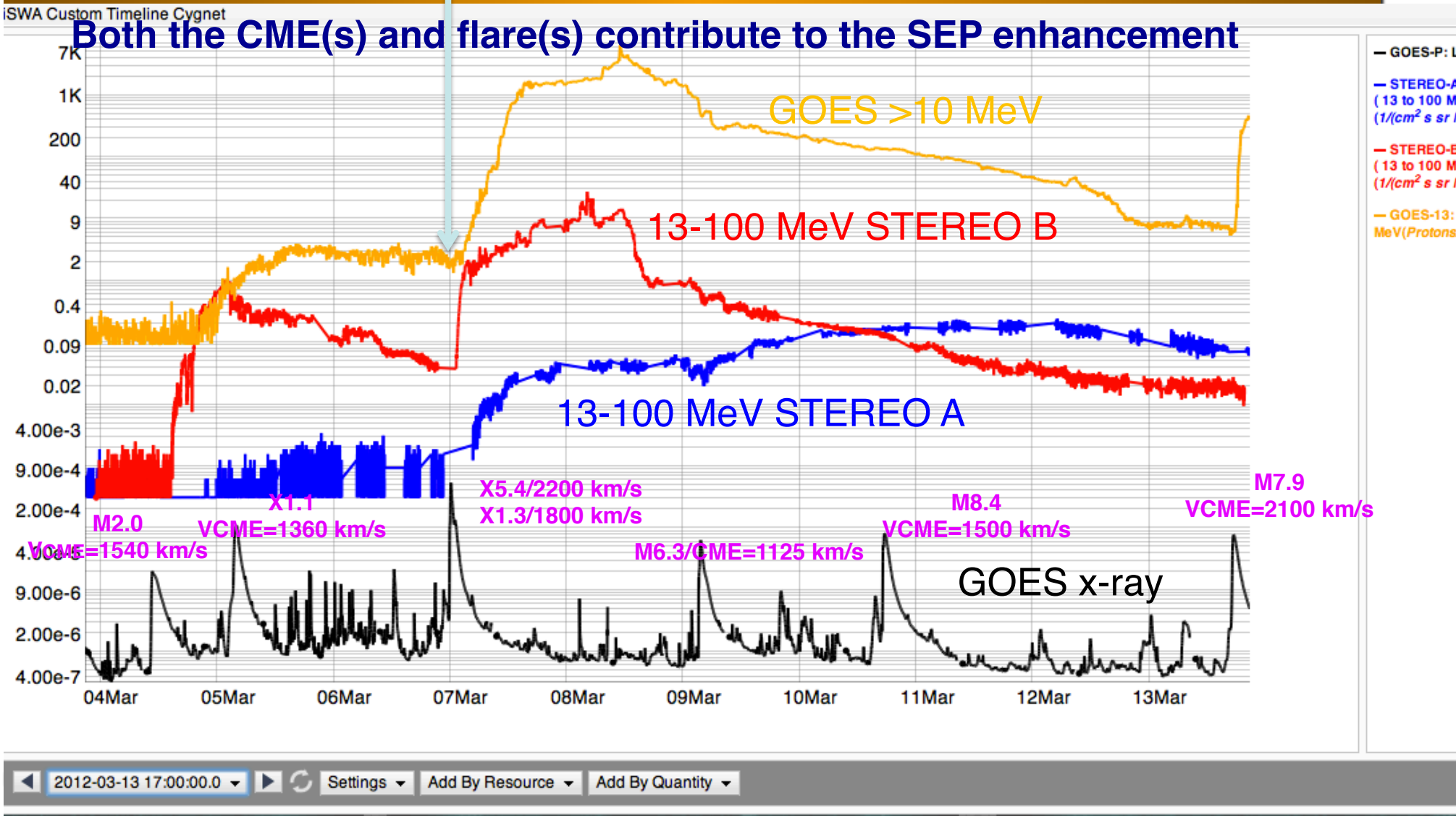


The 7 March 2012 CMEs

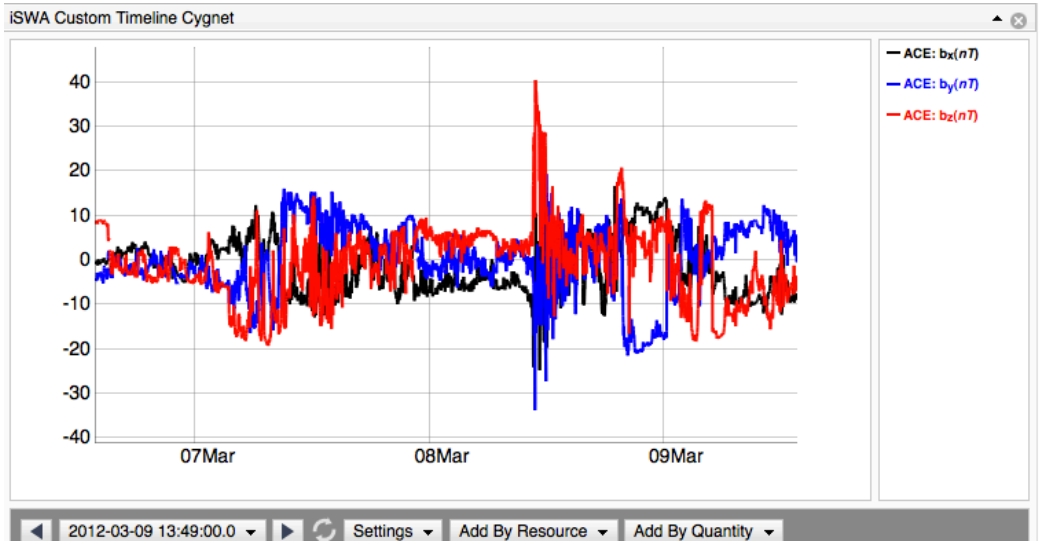


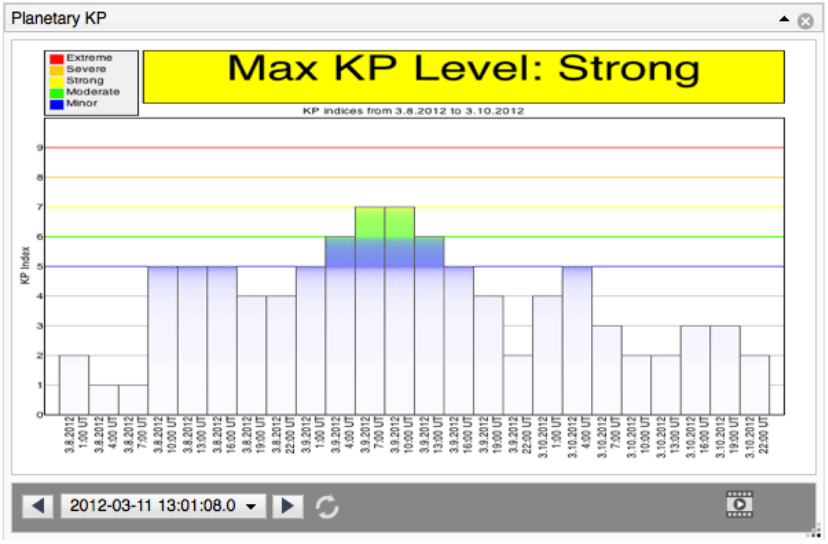

2012-03-06T00:00
2012-03-06T00 +0.00 day
Earth
Mars
Mercury
Venus
Juno
Kepler
Messenger
MSL
Spitzer
Stereo_A
Stereo_B
Ecliptic Plane
LAT = -7.2°
W90
E90
N90
S90
LON = 0°
R = 1.0 AU
W180
E180
0°
R² N (cm⁻³)
0 10 20 30 40 50 60
IMF polarity
Current sheath
3D IMF line
ENLIL-2.7 lowres-2121-a3b1f WSA_V2.2 GONG-2121

SEP: proton radiation



CME impact at Earth



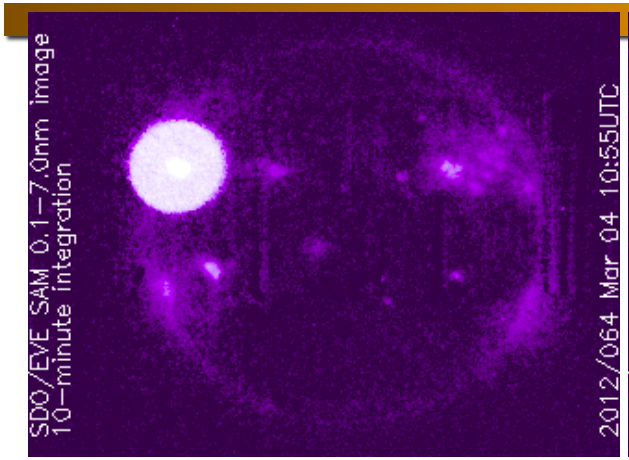


Dstmin = -133 nT

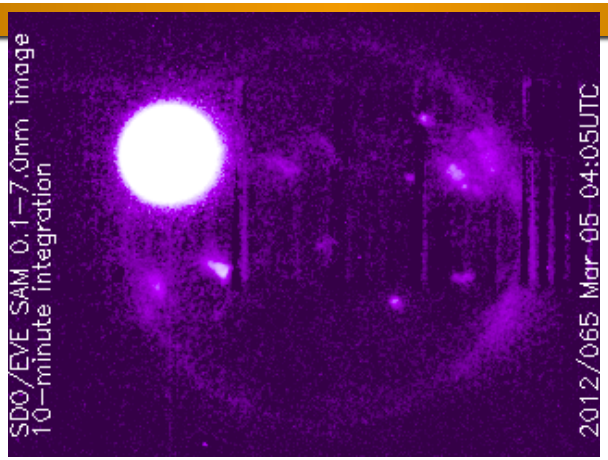
Major events from the long-lasting AR1429 during March 4 – 28, 2012

Flares of the Major Earth-Facing Events viewed by SDO EVE (x-ray)

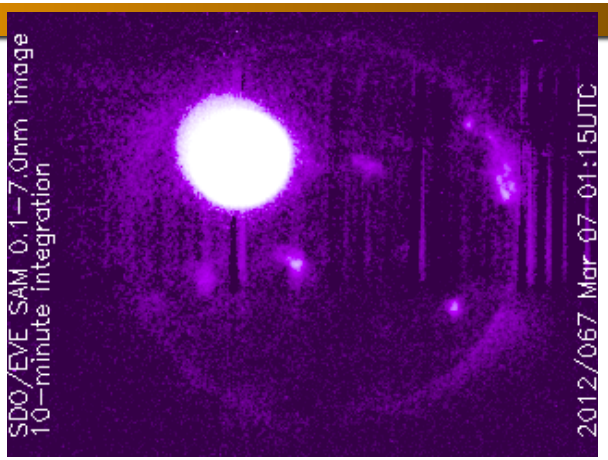
M2.0, 2012-03-04



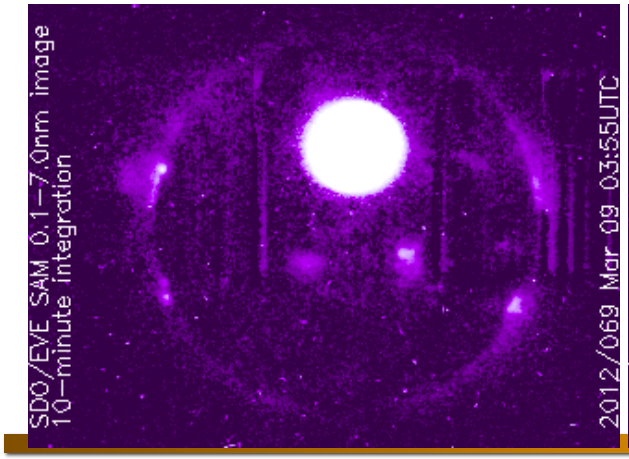
X1.1, 2012-03-05



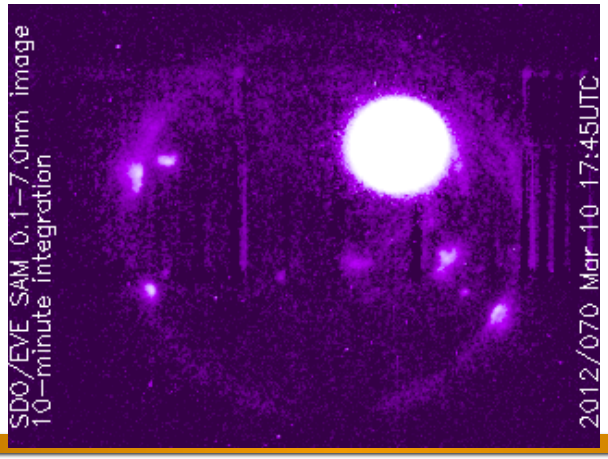
X5.4/X1.3 2012-03-07



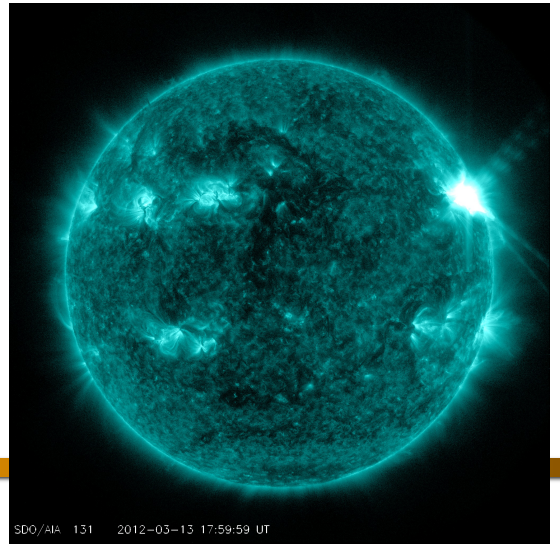
M6.3, 2012-03-09



M8.4, 2012-03-10

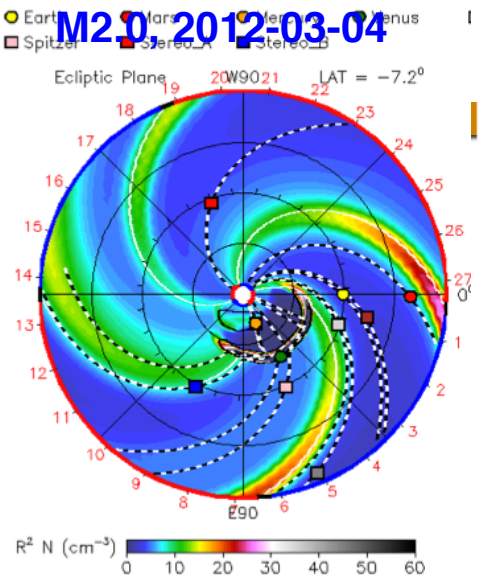


M7.9, 2012-03-13

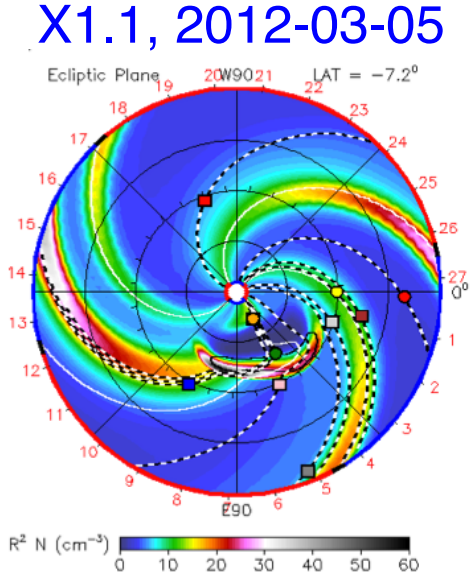


The Corresponding CMEs Associated with the Flares

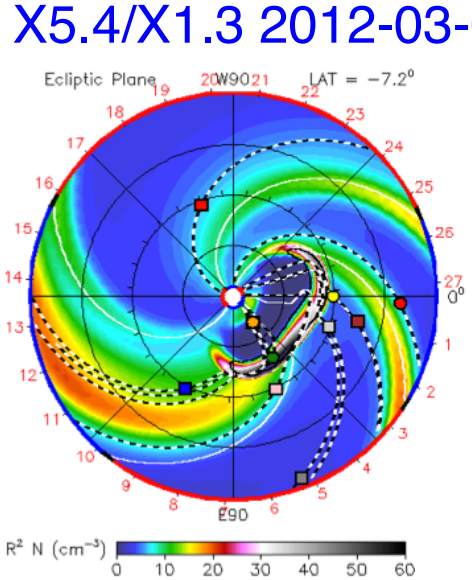
M2.0, 2012-03-04



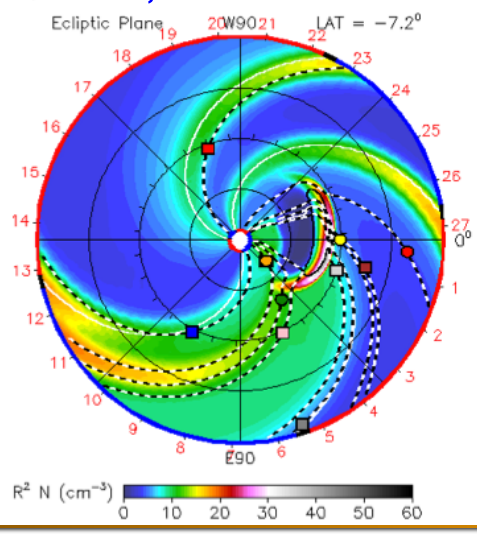
X1.1, 2012-03-05



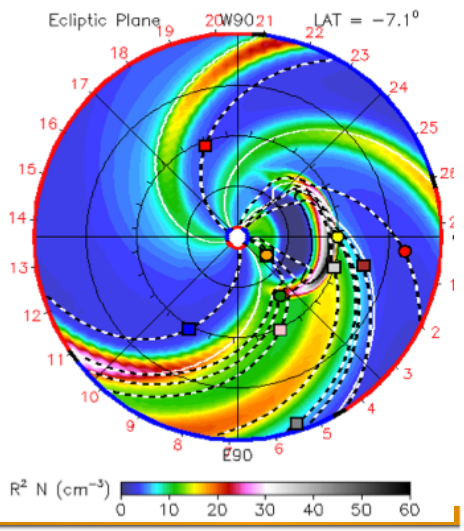
X5.4/X1.3 2012-03-07



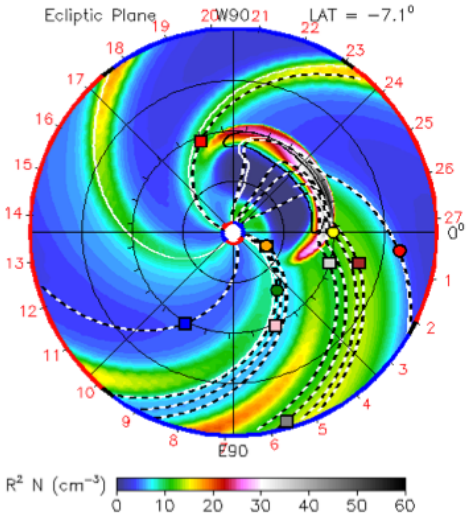
M6.3, 2012-03-09



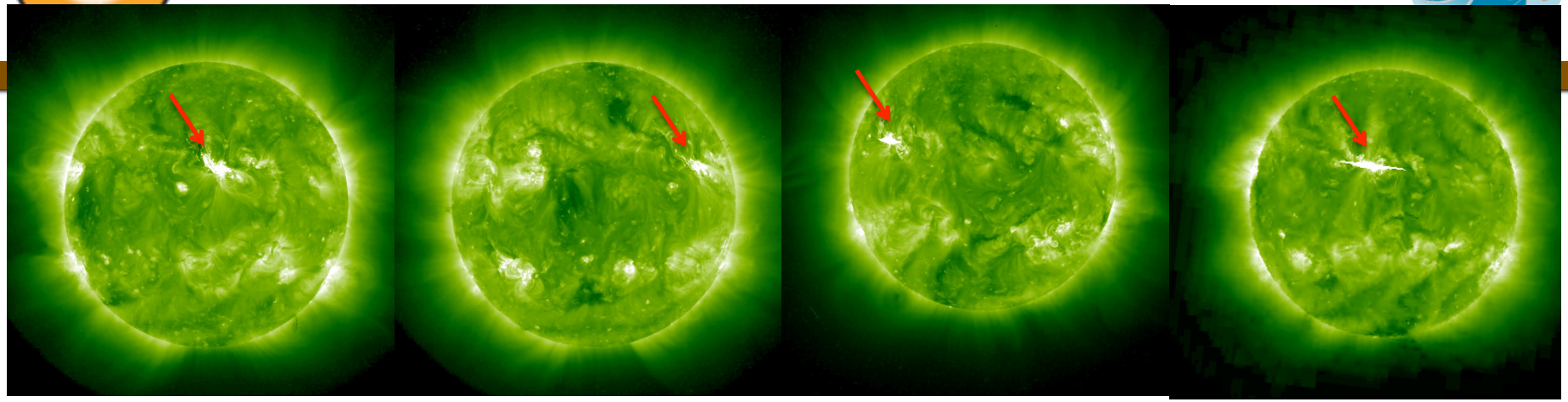
M8.4, 2012-03-10

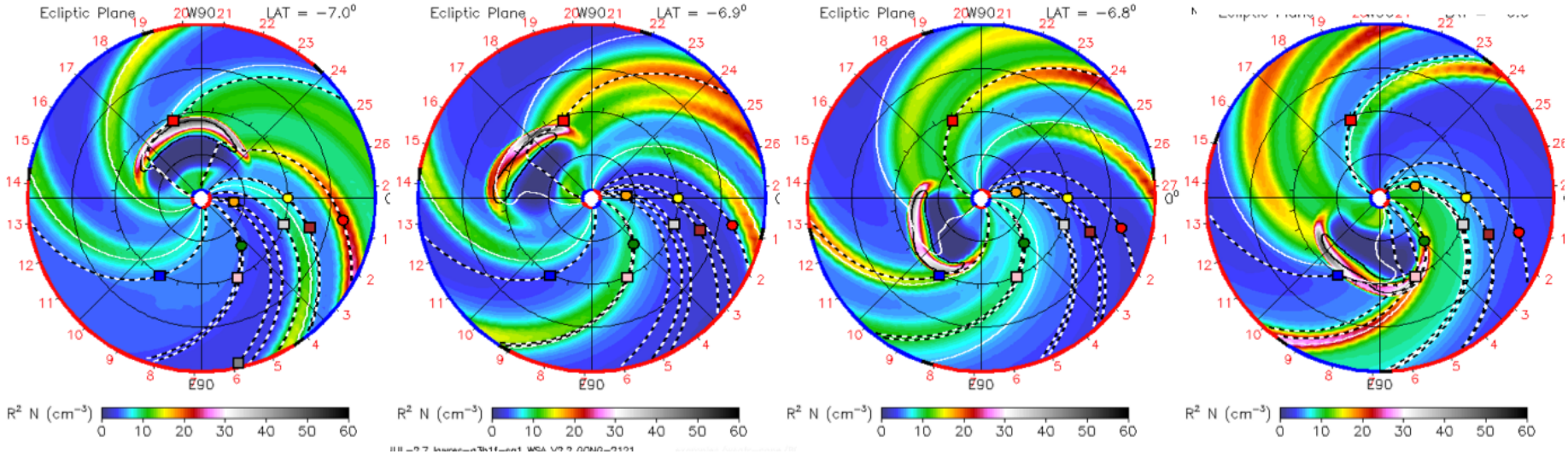


M7.9, 2012-03-13



STA: 2012-03-18 STA: 2012-03-21 STB: 2012-03-24 STB: 2012-03-26





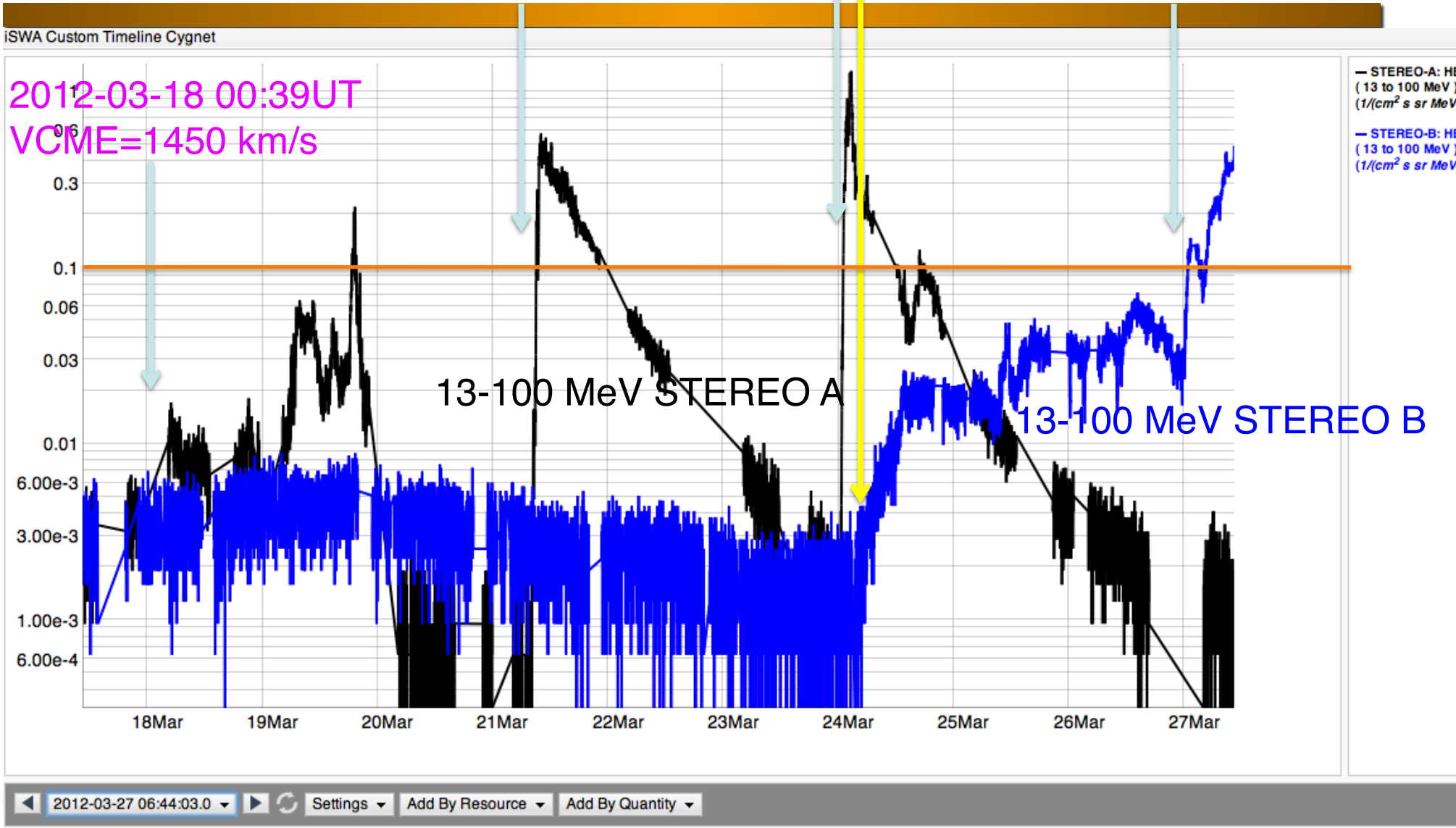
Backsided events in STEREO EUVI 195A (top) and CME model simulations (bottom)

Enhanced proton radiation at STEREO A and B from the backsided events.

2012-03-21 07:39 UT
VCME=1550 km/s

2012-03-24 00:39UT
VCME=1600 km/s

2012-03-26 23:12UT
VCME=1500 km/s



Supplementary Material

- View our video, Incredible Active Region 1429: One for the record books, to learn more about the activities from this region from March 4 – March 28, 2012.
  http://youtu.be/PbyJswbX4VA
- This video has been updated at the following link:
  http://youtu.be/dxl5drPY8xQ
  (And also available on http://vimeo.com/nasaswc/ar1429)
- Summary Video of the March 7, 2012 event
  http://youtu.be/HeoKf6NfEJI
  Full text of event summary
  http://goo.gl/dTnfd

NASA Space Weather Research Center

http://swrc.gsfc.nasa.gov/

Part II

Spacecraft Anomalies due to the March Solar Activities

Acknowledge: feedback from people involved in robotic missions

Interplanetary mission MESSENGER

- 11 instances of anomalous behavior have been identified to be associated with the increased solar activity in early March 2012.
- The spacecraft attitude control system (ACS) and 5 of the seven science instruments were temporarily affected, but all were quickly returned to nominal operations.
- The Magnetometer (MAG) and the Mercury Laser Altimeter (MLA) were the only instruments that showed no adverse effects.

Interplanetary mission MESSENGER

- MESSENGER/FIPS (The Fast Imaging Plasma Spectrometer) experienced ~ 7 SEU in its flight software memory, one of which was critical to require reboot
- The instrument microchannel plate bias voltage spontaneously lowered below the threshold (at 2012-03-07T 04:40 UT, shortly after the two x-class flare/CME/SEP event) where counting takes place. So all data collection stopped.

Interplanetary missions

- WIND/SMS(STICS and MASS) – reset by internal latchup detection, manually restored on 8 March.
- ACE– no solar wind plasma measurements

Earth mission

- CALIPSO
  - 07 March 2012 08:10 UTC Payload commanded to 'SAFE' mode in response to eruption of Class X5.4 flare
  - 13 March 2012 12:18 UTC Restarted payload computer
  - 13 March 2012 22:56 UTC Payload commanded to 'SAFE' mode in response to eruption of Class M7.9 flare
  - 19 March 2012 11:47 UTC Payload Computer restarted
  - 20 March 2012 16:39 UTC Lasers restarted and normal measurement operations resumed

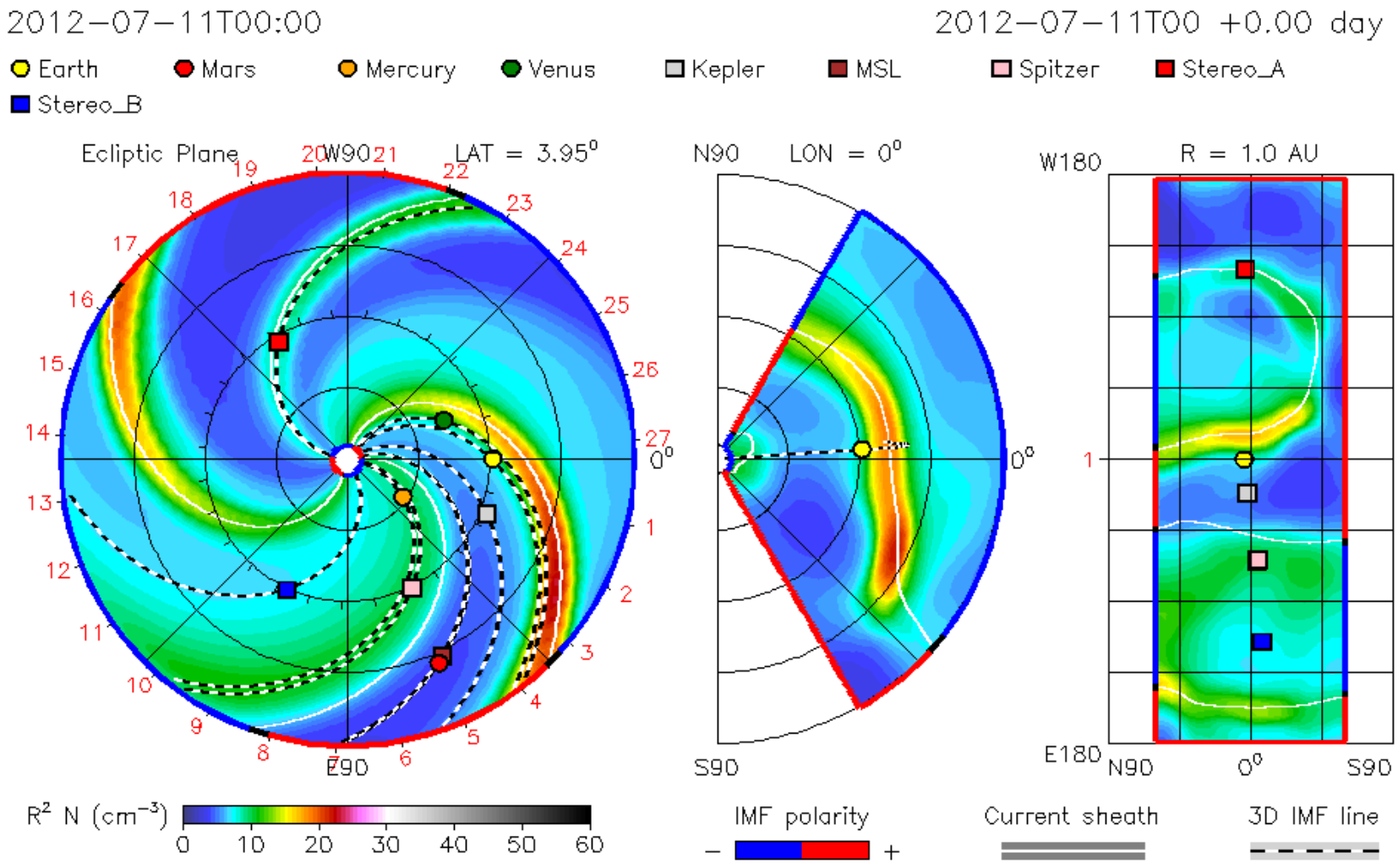
The CALIPSO payload computer and laser are sensitive to enhanced levels of energetic heavy ions. Significant damage to either of these components is considered a high risk and a threat to the mission.

Forecasting Earth-Directed CME and its impact
the 12 July 2012 solar eruption

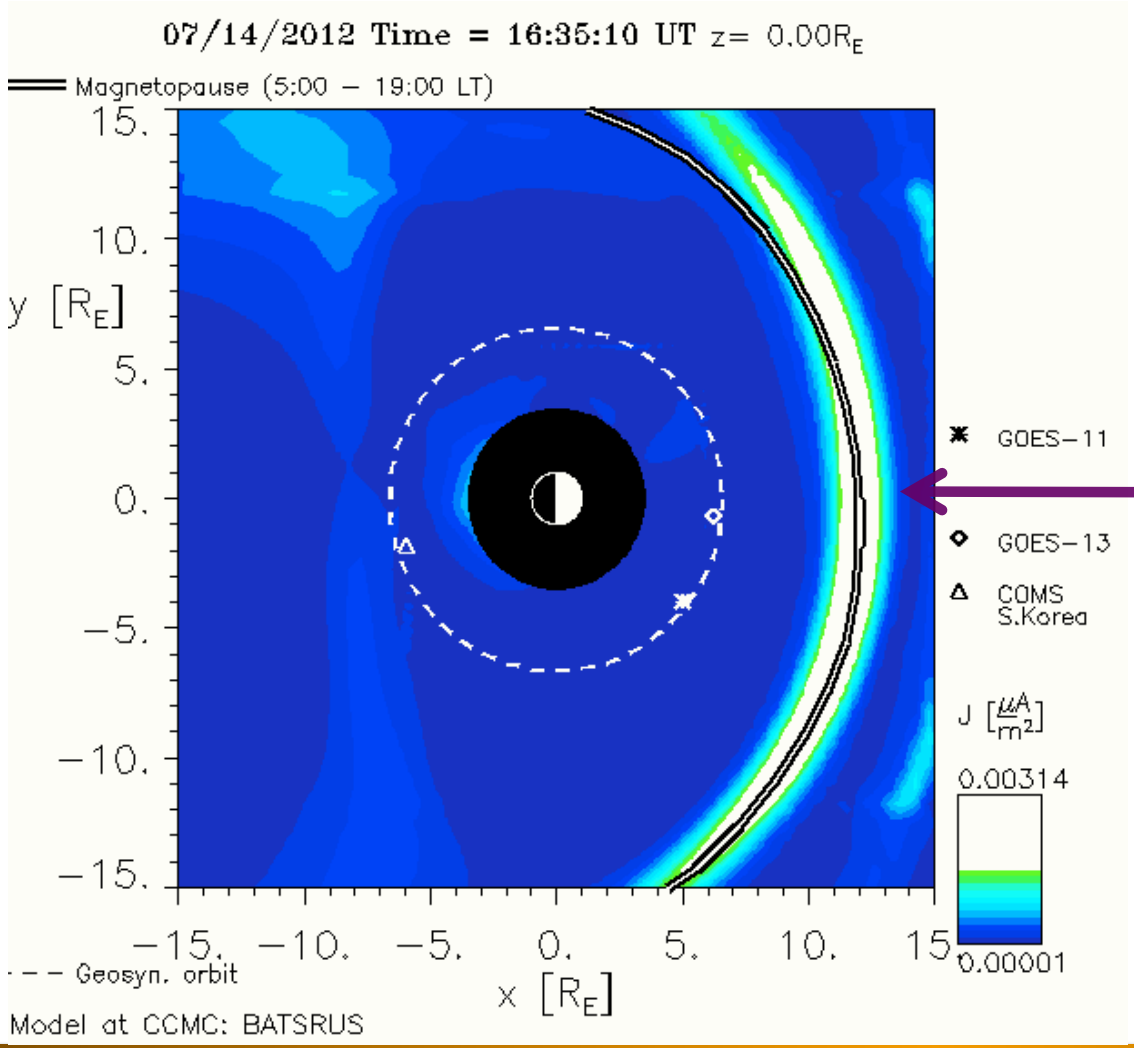
a minor radiation storm (SEP)
But a major geomagnetic storm

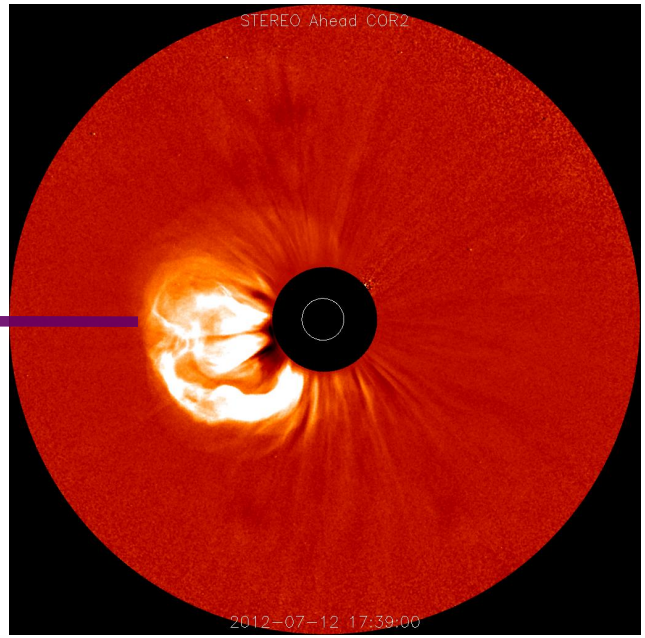
Modeling of the 12 July 2012 CME

V=1400 km/s, associated with an X1.4 class solar flare



Earth's Response to the CME's Arrival

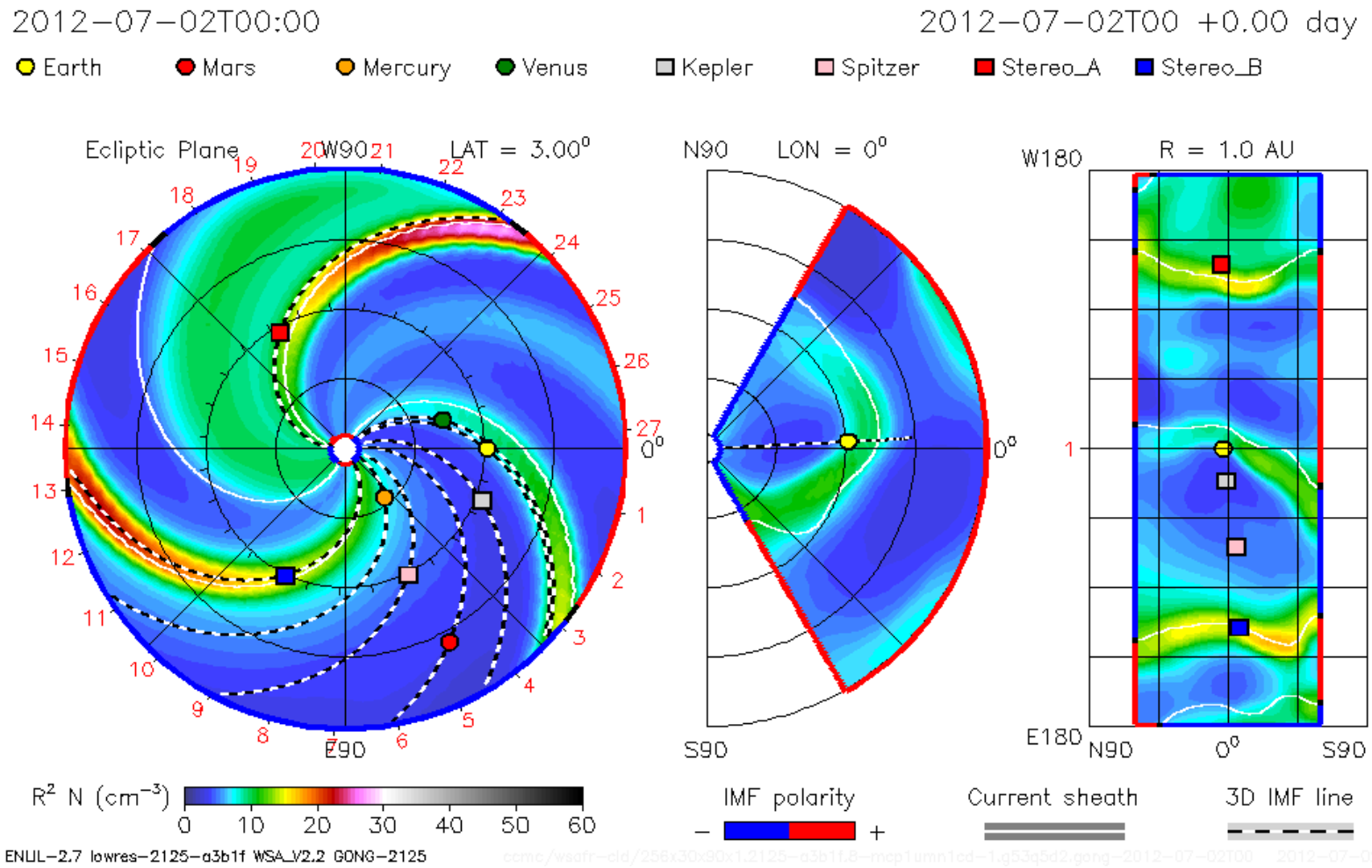




The CME seen by STEREO A

Resulting in a Kp = 7- on a scale from 0 – 9, Kp: a measure of geomagnetic disturbances

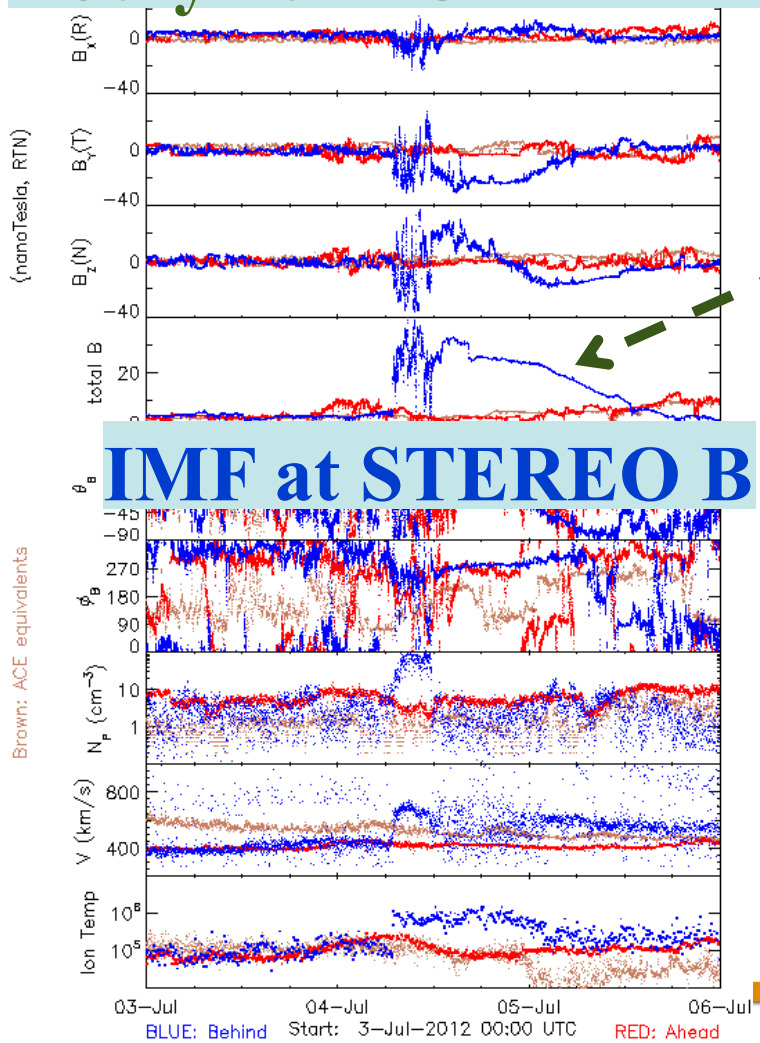
2 July 2012 CME heading towards STEREO B



History of the same active region

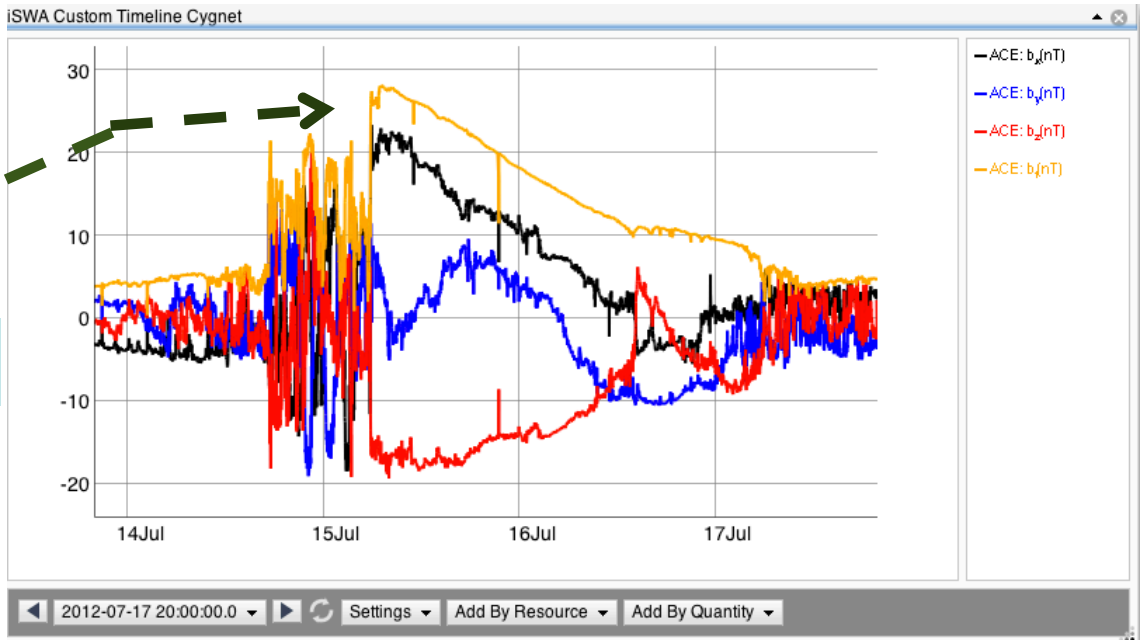
History of the Active Region CME Arrival at STEREO B

2 July 2012 CME arrival



IMF at STEREO B

IMF at ACE

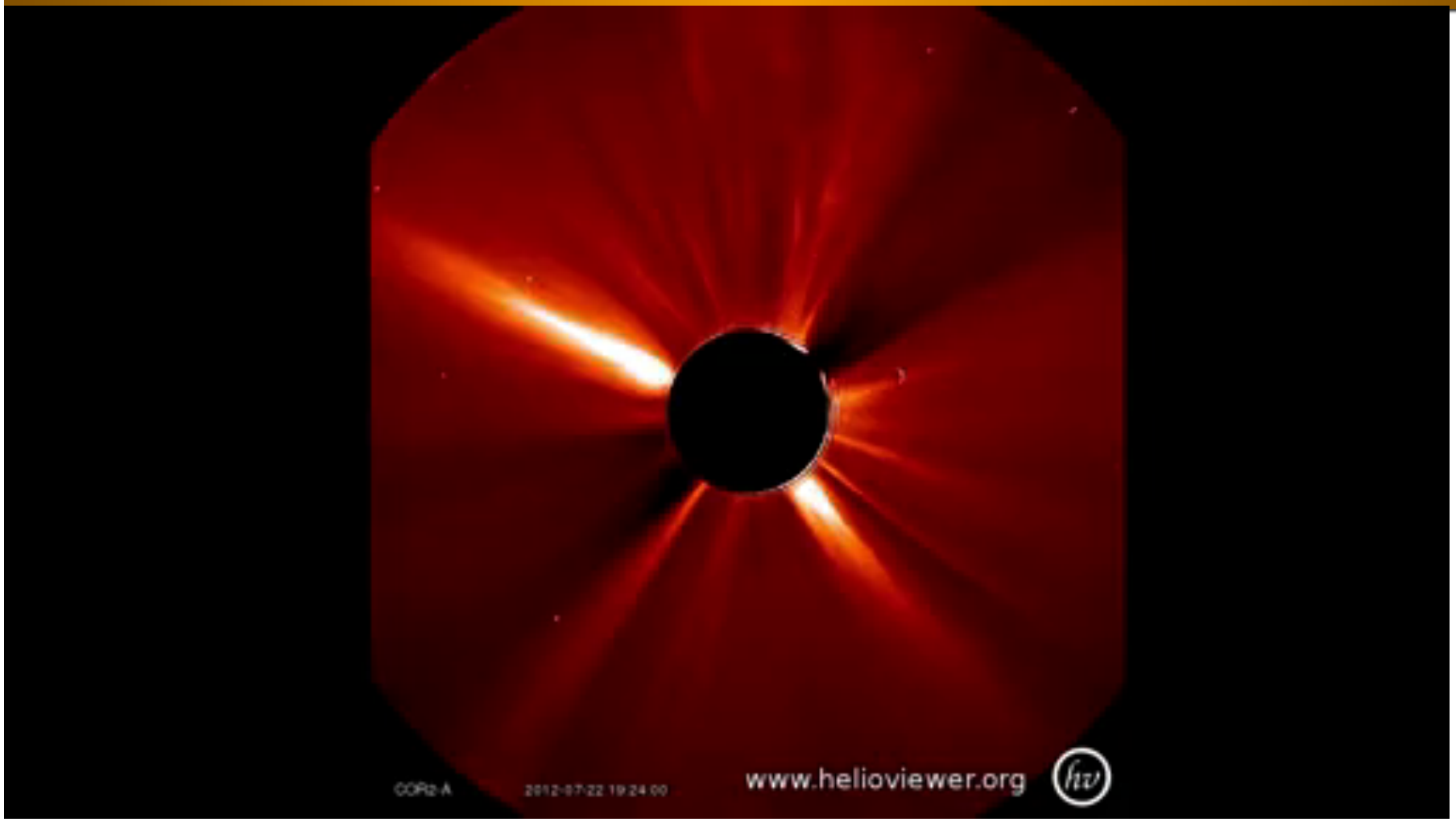


The 12 July 2012 CME arrival @ ACE

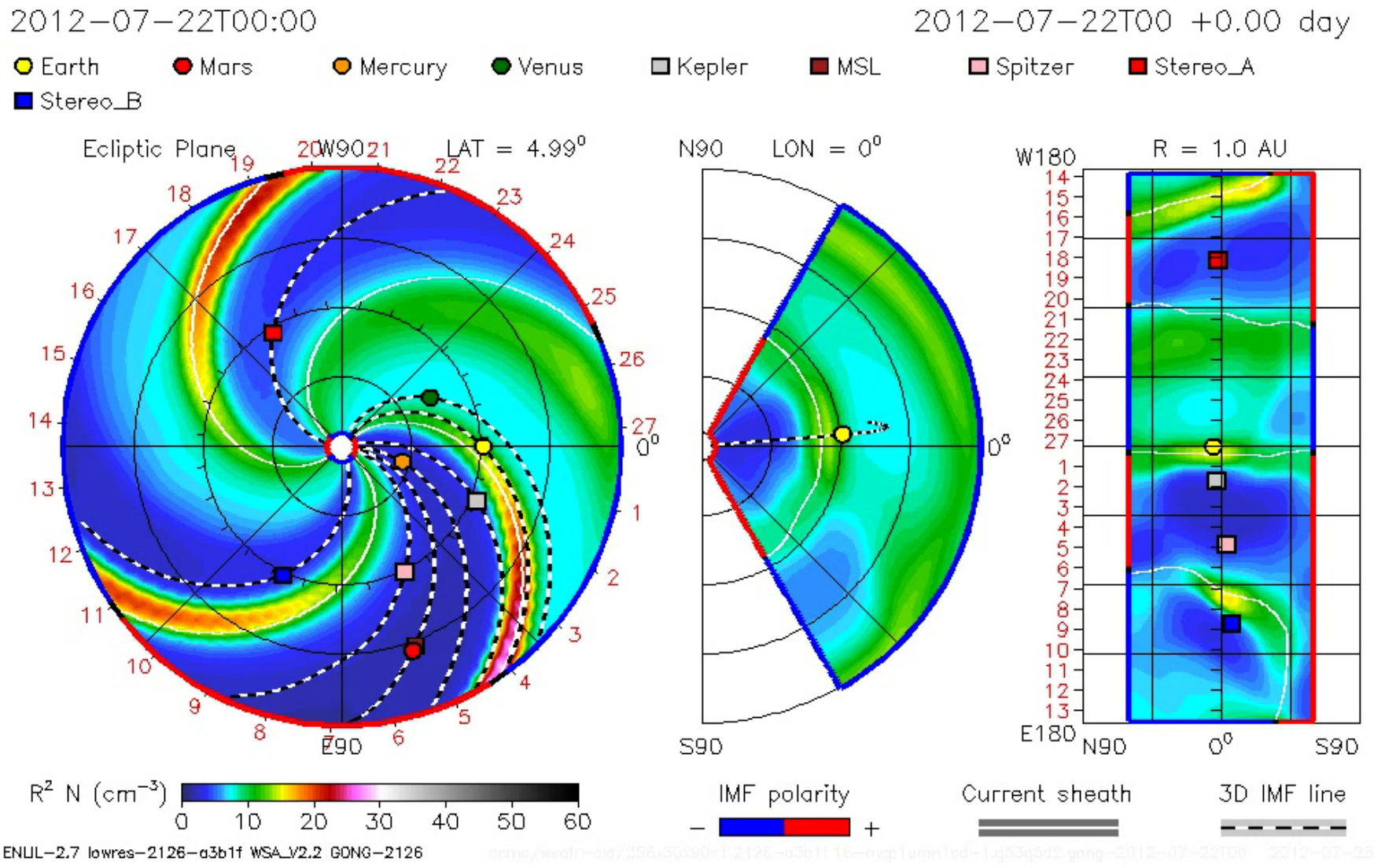
The 23 July 2012 event

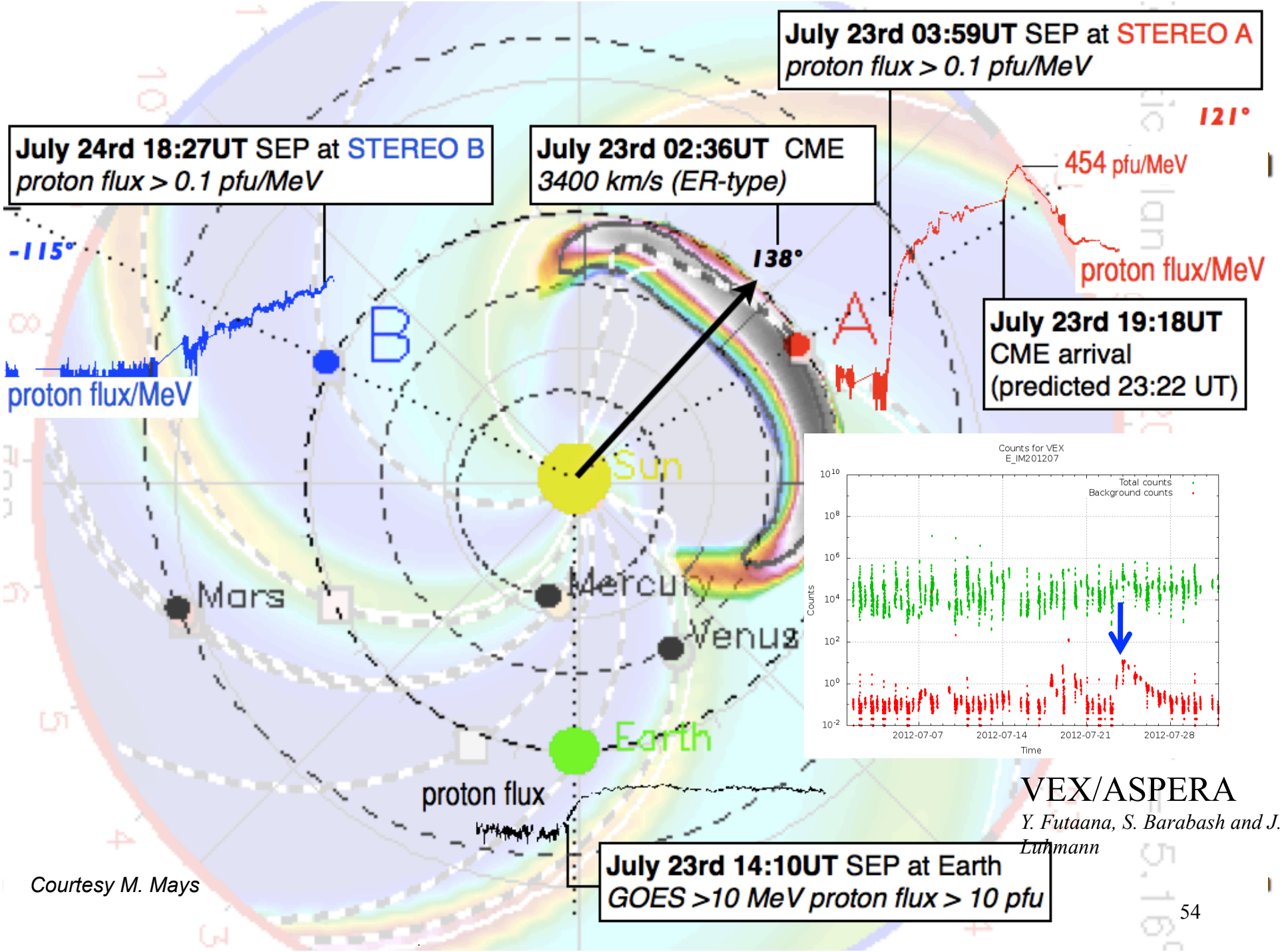
One of the extreme SEP events on record
One of the fastest CMEs ever been observed - 3400 km/s
Travelled 1 AU distance in ~ 17 hours

- July 23 CME viewed from STEREO A



- Real-time Simulation of the July 23 CME





VEX/ASPERA

Y. Futaana, S. Barabash and J. Luhmann

Courtesy M. Mays

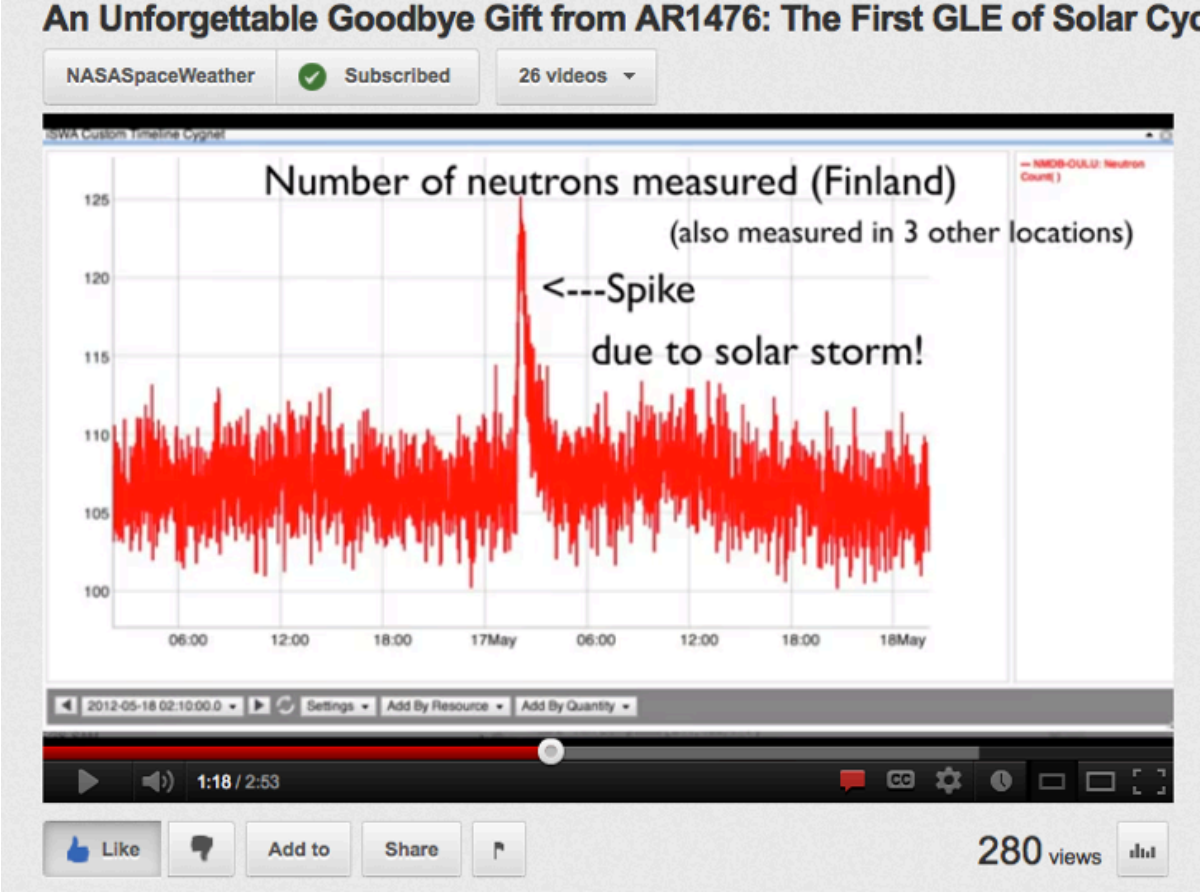
- All the July 2012 events were from AR 1520

1st and only GLE event of Solar Cycle 24

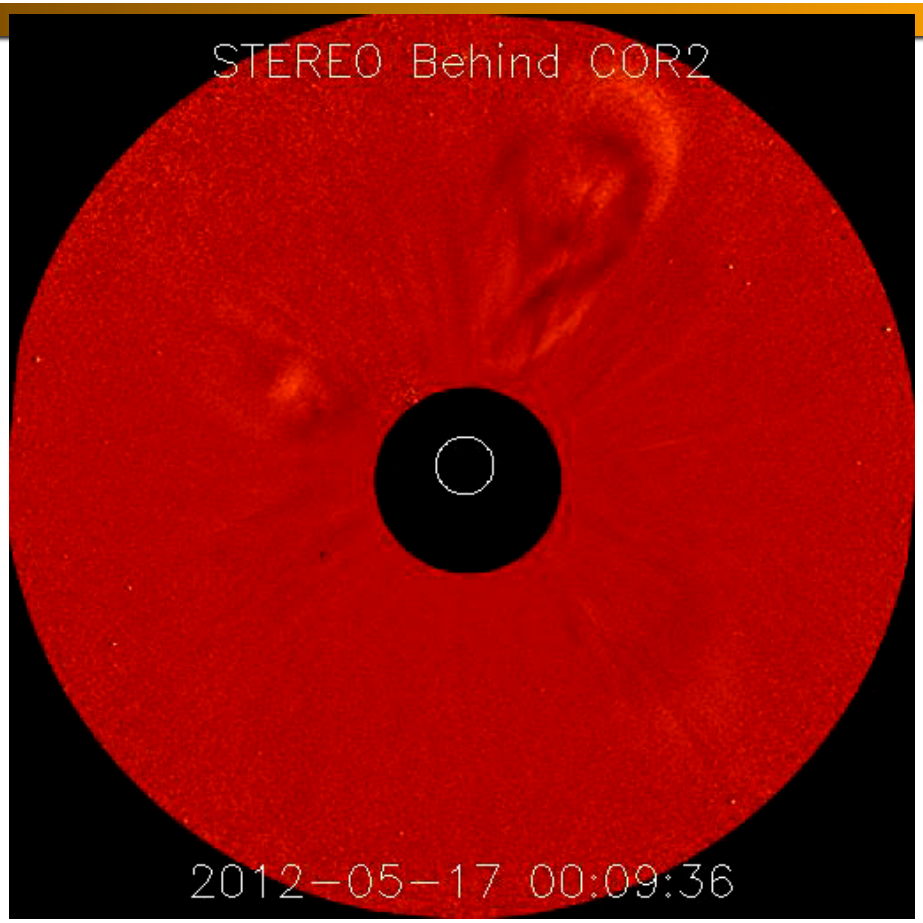
Ground Level Enhancement (GLE) - subset of SEP events

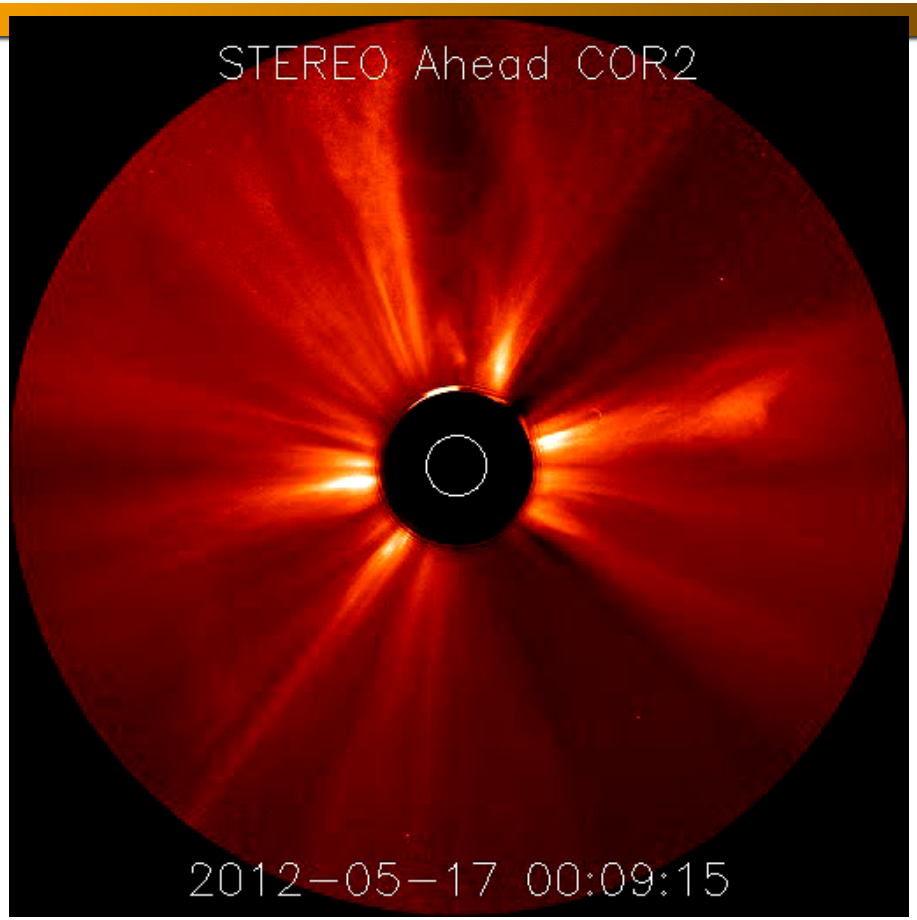
AR 1476 -- M5.1 flare @ 01:47 on **2012-05-17**

9 bursty short-lived M-class flares during May 5 - 10

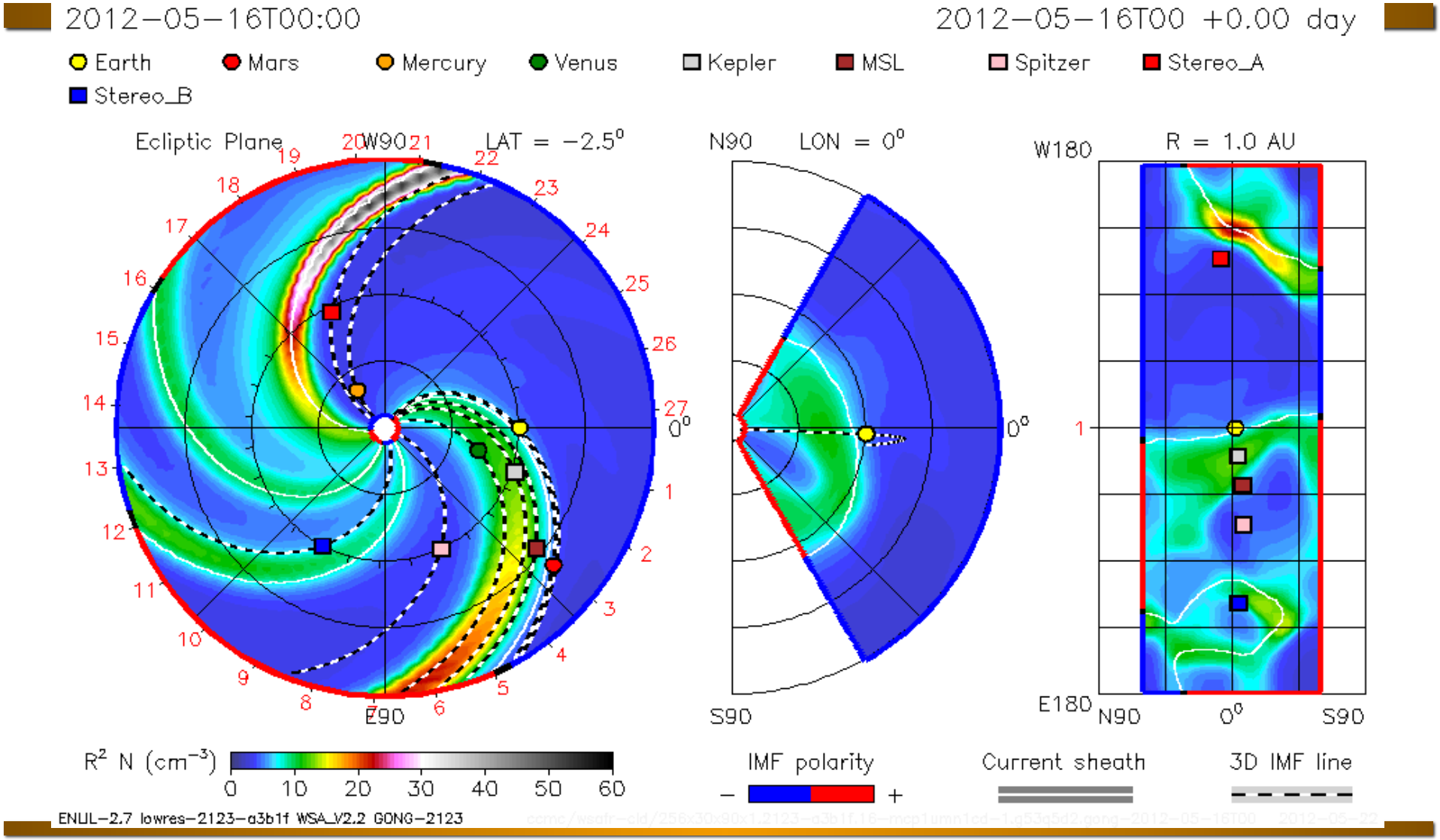


- Associated CME with the GLE Event





•Simulation of the CME(s)



Space Weather Event Logging System

DONKI

- Forecasters log space weather events and activities
- Allow events/activity chains, establish cause and effect relationships
- Multi user/forecaster system designed to promote community involvement
- Entry point for initiating alerts, cataloging events
- Knowledge management system for human generated logs, analysis